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EVALUATION OF SEISMIC INSTRUMENTS

AND

BASIC RESEARCH ON SEISMIC WAVE PROPAGATION

Blaney, Joseph I.   Devane, S.J., John F. (PI)

Trustees of Boston College
Chestnut Hill, Mass. 02167

Contract No. AF19(628)-6067

Project No. 8652

Task No. 865207

Work Unit No. 86520701

ANNUAL REPORT NO. 1

Period Covered: June, 1966 - May, 1967

June 30, 1967

Contract Monitor: Henry A. Ossing
Terrestrial Sciences Laboratory

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This research was supported by the Advanced Research Projects Agency under ARPA Order No. 292, Amendment No. 32

Prepared for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
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ABSTRACT

This report contains a complete description of a Portable FM Seismic Transmitting and Receiving System capable of unattended operation. It is specifically designed to broaden the capabilities of the portable seismic system developed under Contract AF19(628)-212. Each Seismometer signal is preamplified and conditioned for FM transmission. The receiver recovers the signal and conditions it for recording, either directly or on magnetic tape.

A computer controlled system for the calibration of seismometers is described. The end product is a response curve in terms of both amplitude and phase.

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Section 1

EQUIPMENT DESCRIPTION

A. GENERAL DESCRIPTION

The Portable FM Seismic Transmitting and Receiving Station is an unattended system operating in the 150 MC region and designed to work in conjunction with, and broaden the capabilities of the PORTABLE SEISMIC SYSTEM repackaged by Weston Observatory under Contract AF19(628)-212. It can be used independent of the Portable System but does not contain any recording capability.

Each seismic signal is preamplified by a reactance amplifier stepped up through a high gain amplifier, is conditioned and FM transmitted. The receiving unit recovers the signal and conditions it for recording. At this point the system may be monitored as a standard telemetry system, and be directly recorded, or the signal may be fed into the Portable Seismic System where it will be further conditioned and FM recorded on magnetic tape.

B. MECHANICAL DESCRIPTION

Both units are housed in identical aluminum cases measuring 18" x 13" x 8", less external hardware (See Figure 1). The transmitter package weighs 16 pounds. The

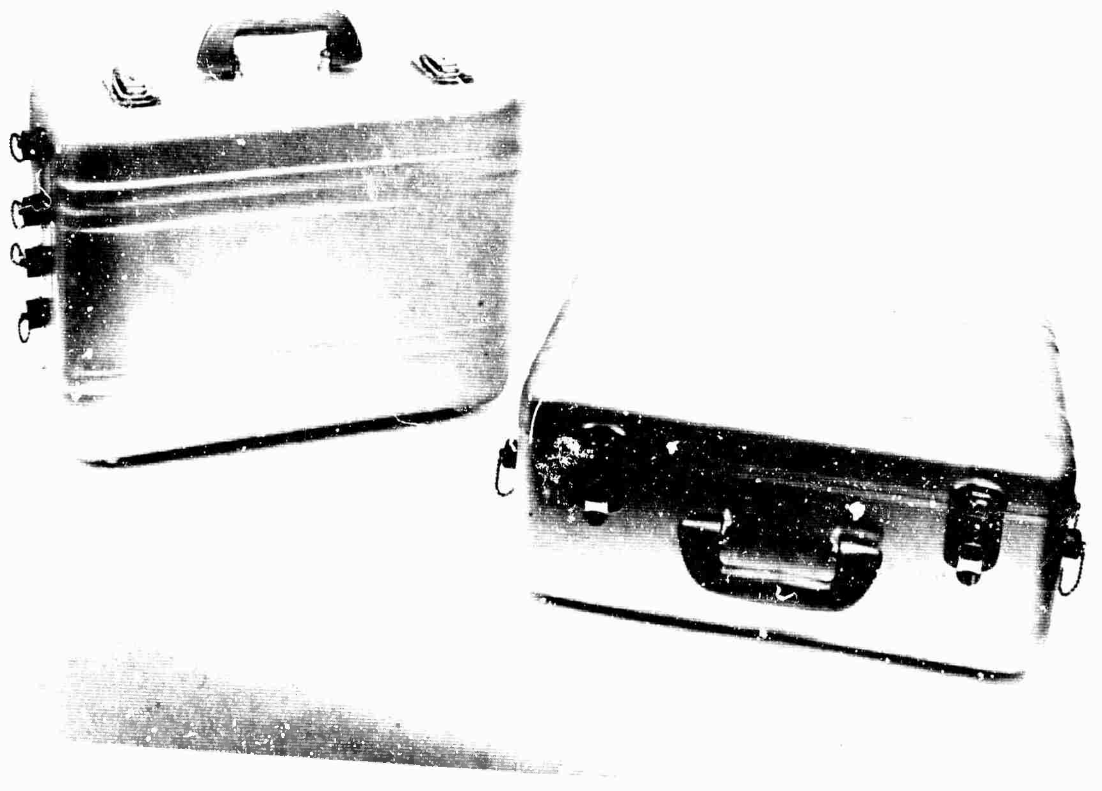


Figure 1

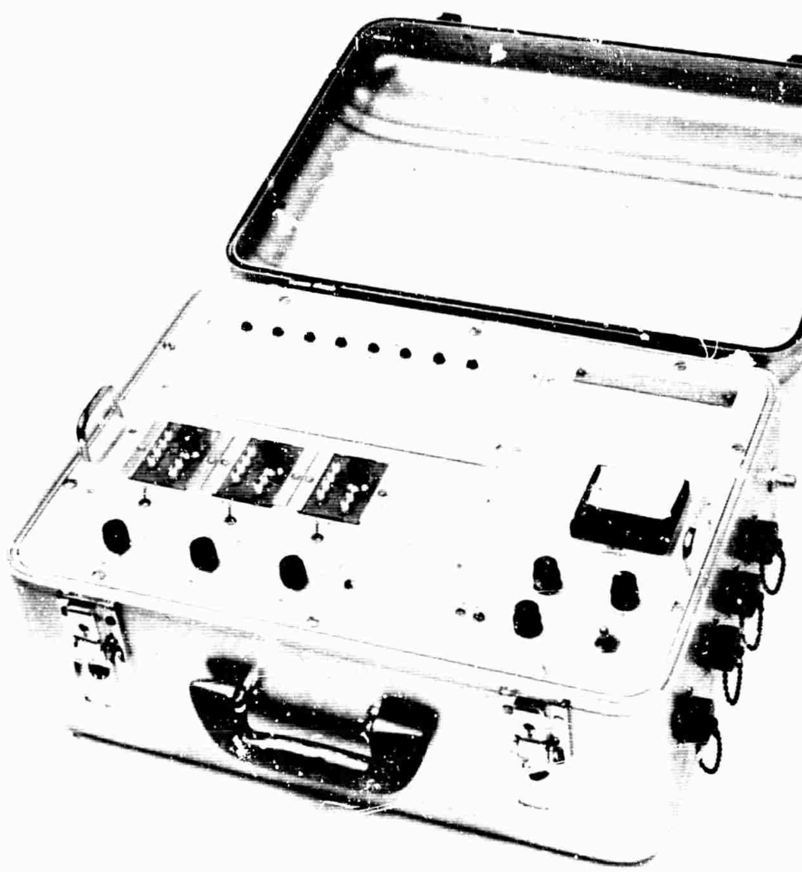


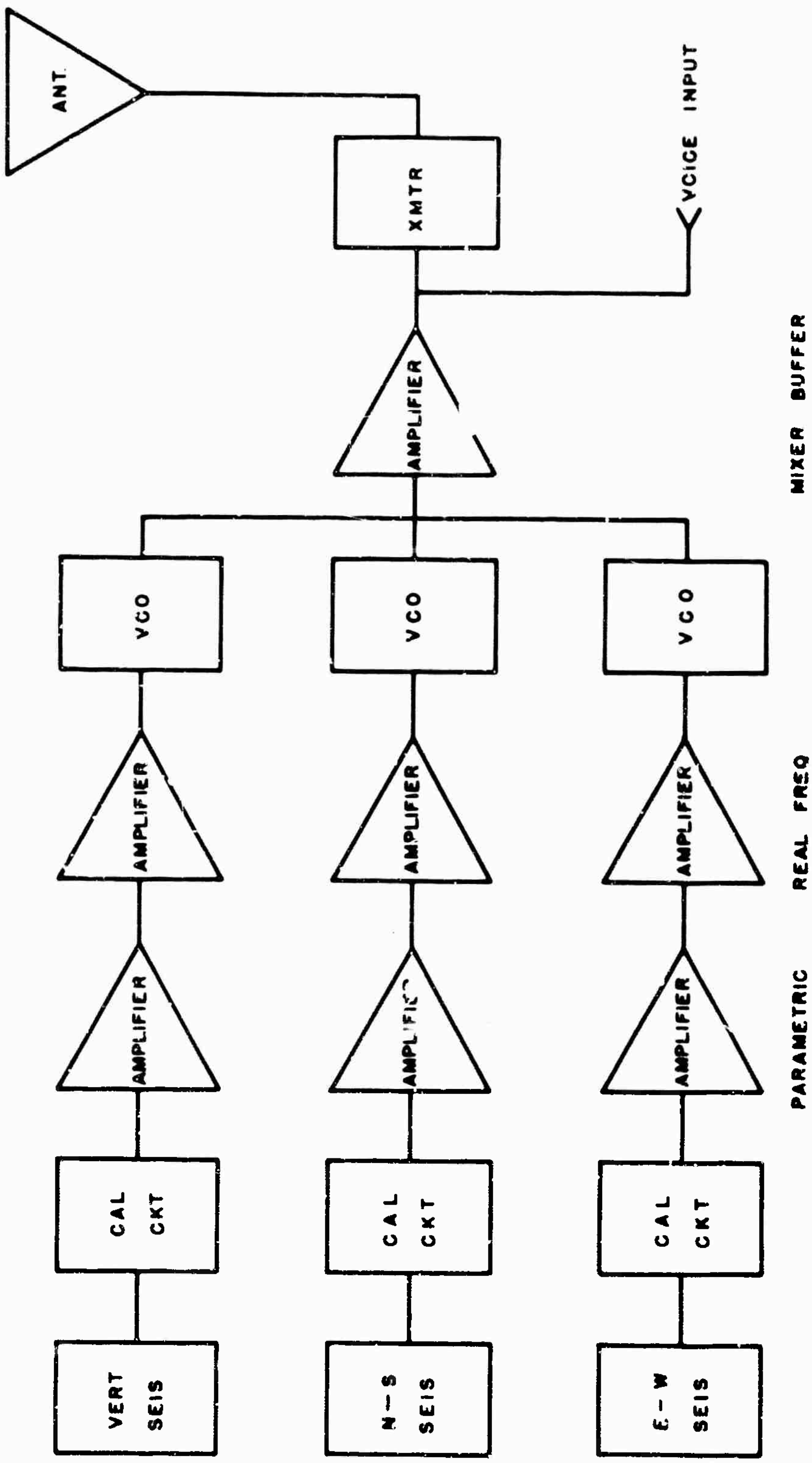
Figure 2

Figure 3

receiver package weighs 19 pounds. Figures 2 and 3 show the mechanical layout of the transmitter and receiver units respectively.

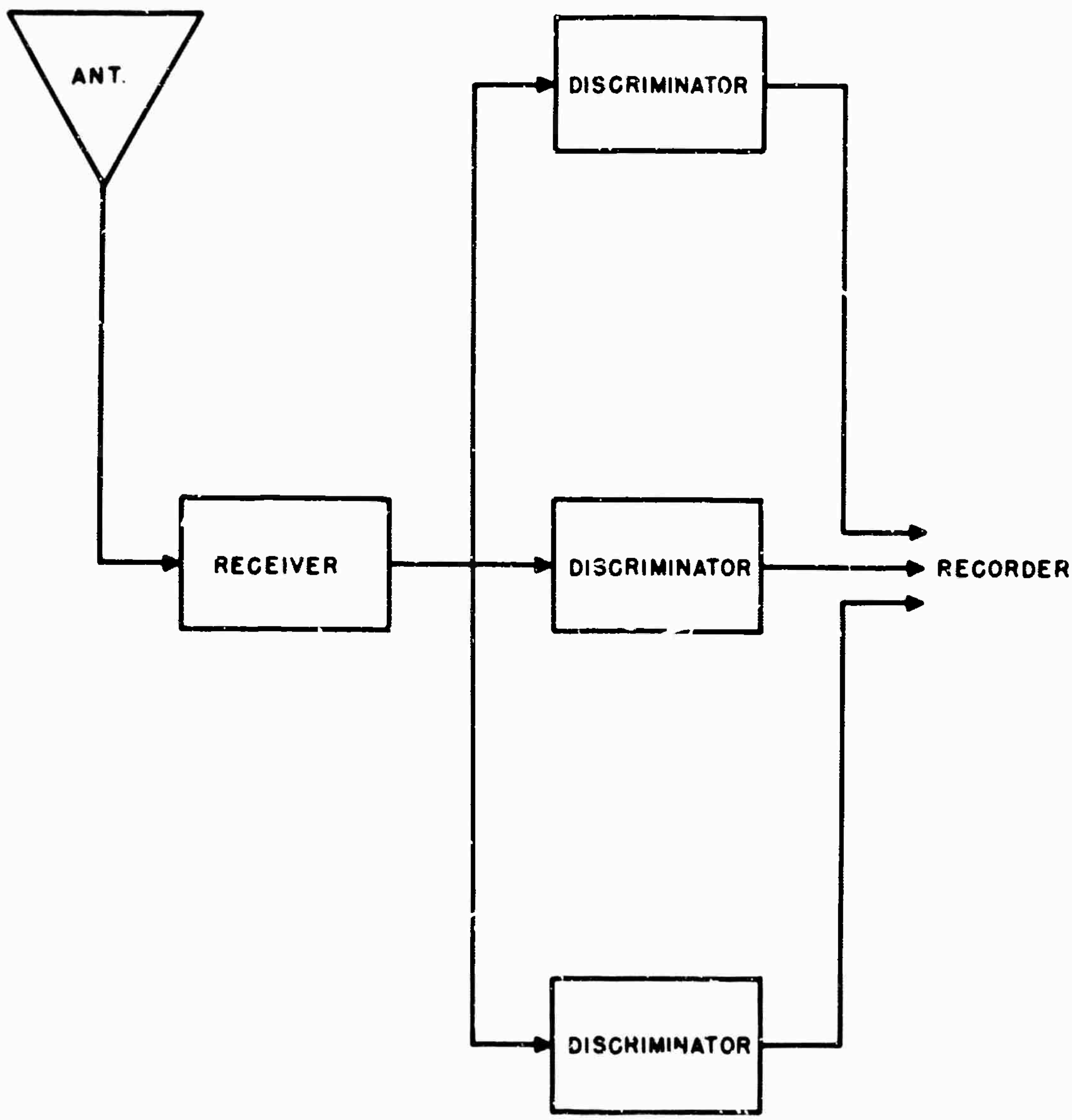
C. SYSTEM BLOCK DIAGRAM

The block diagram of the Portable FM Transmitting and Receiving Stations, Figure 4, illustrate the functional arrangement of the system. The signal goes unaltered through the calibrate circuit, which at present must be manually activated, and into the parametric, or reactance amplifier. This amplifier is used as an adjustable high gain preamplifier with a nominal voltage gain of 66 db. The input attenuator of this amplifier is used to terminate the seismometer at 13.6 KΩ, which is the 0.70 critical damping point of the Electrotech EV17 5000Ω seismometer being used. The output of this amplifier is fed into a single ended fixed gain, real frequency amplifier which conditions the signal to drive a voltage controlled oscillator. The outputs of the three VCO's in the system are high impedance mixed and reamplified to drive the FM transmitter unit. The RF signal is then transmitted to the receiver by a high gain directional antenna system. The receiver unit detects the multiplex signal and feeds it to a bank of discriminators. The outputs of the discriminators may be directly recorded or patched over to the Portable Seismic System.



PORTABLE SEISMIC TRANSMITTING STATION

FIGURE - 4



PORTABLE SEISMIC RECEIVING STATION

FIGURE - 4(A)

Table I

Characteristics of FM Telemetry System

SENSORS	3 Electro-Tech EV17 Seismometers 1 Vertical 2 Horizontal
SYSTEM SENSITIVITY	1 Milli-micron at 1 CPS
FREQUENCY RESPONSE	0.8 - 8.4 CPS
DYNAMIC RANGE	50 db
SENSOR CALIBRATION	Manual - internal Adjustable in amplitude
RF SECTION	
POWER OUTPUT	2.0 watts
RECEIVER SENSITIVITY	0.5 μ volts
RANGE	≈ 10 miles
FREQUENCIES	150.27 Mc 150.30 Mc 150.33 Mc
BANDWIDTH	5 Kc
SIZE	18 x 13 x 8 less hardware
WEIGHT	
RECEIVER	19 lbs.
TRANSMITTER	16 lbs.

D. SYSTEM DESCRIPTION

1. Seismometers

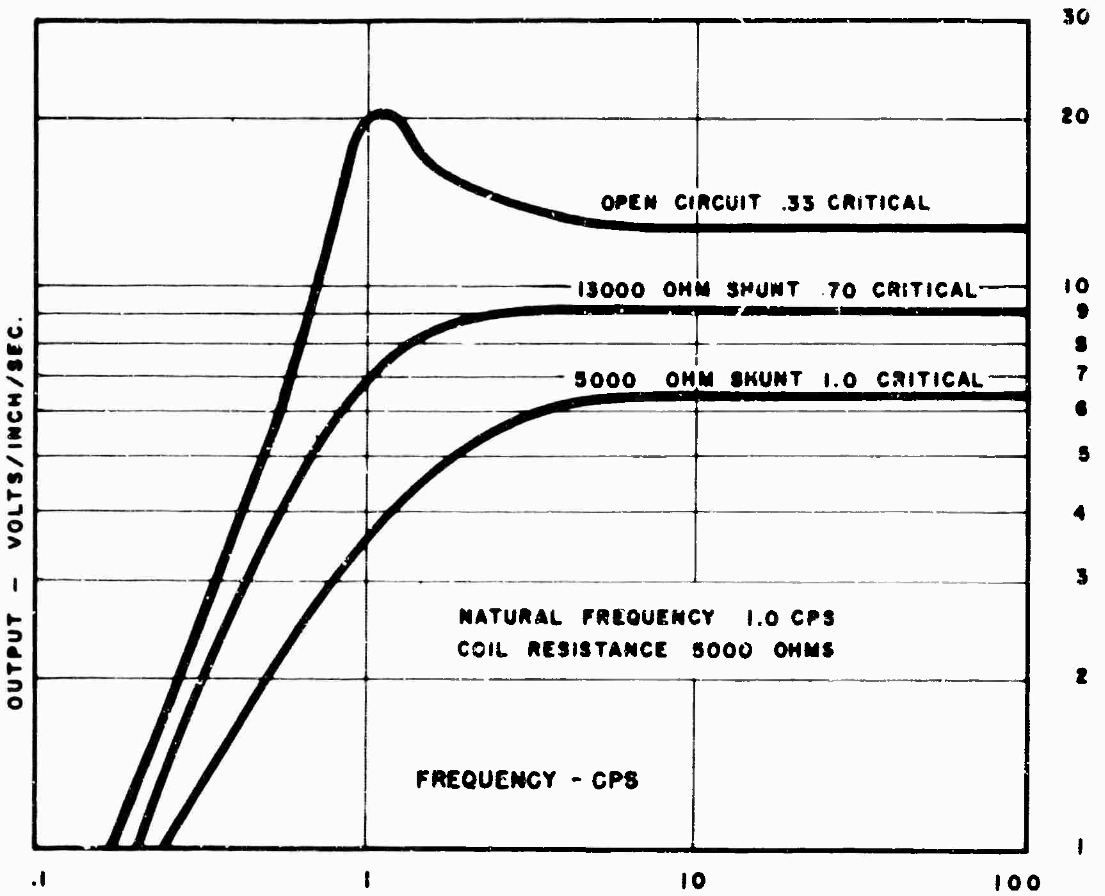
The seismometers used with this system are the Electro-Technical Labs Model EV17. Its rugged construction incorporates a variation of the inclined spring suspension design that requires no clamping. A viewing window allows the relative beam position to be readily ascertained. A bale handle provides an easy means of carrying the seismometer.

The natural undamped frequency is 1.0 cps. Any damping from .33 (open circuit) to 1.0 may be obtained with the proper shunting resistor. Open circuit sensitivity is 480 volts/meter/sec. (Figure 5) The moving mass weight is 2760 grams with an excursion of ±2 mm or more. The seismometers will operate at tilt angles up to 2° in all directions. The vertical seismometer is 5½" x 9" x 6" high, weighing approximately 13 pounds; the horizontal seismometers are 6½" x 10" x 6" high, weighing approximately 15 pounds.

2. Amplifier Section

An extremely low-noise amplifier is necessary (internal noise level of 0.1 microvolt or less) along with high-input impedance to achieve the required sensitivity for seismic signals.

A four section, low frequency amplifier is provided with the necessary characteristics. The first section utilizes



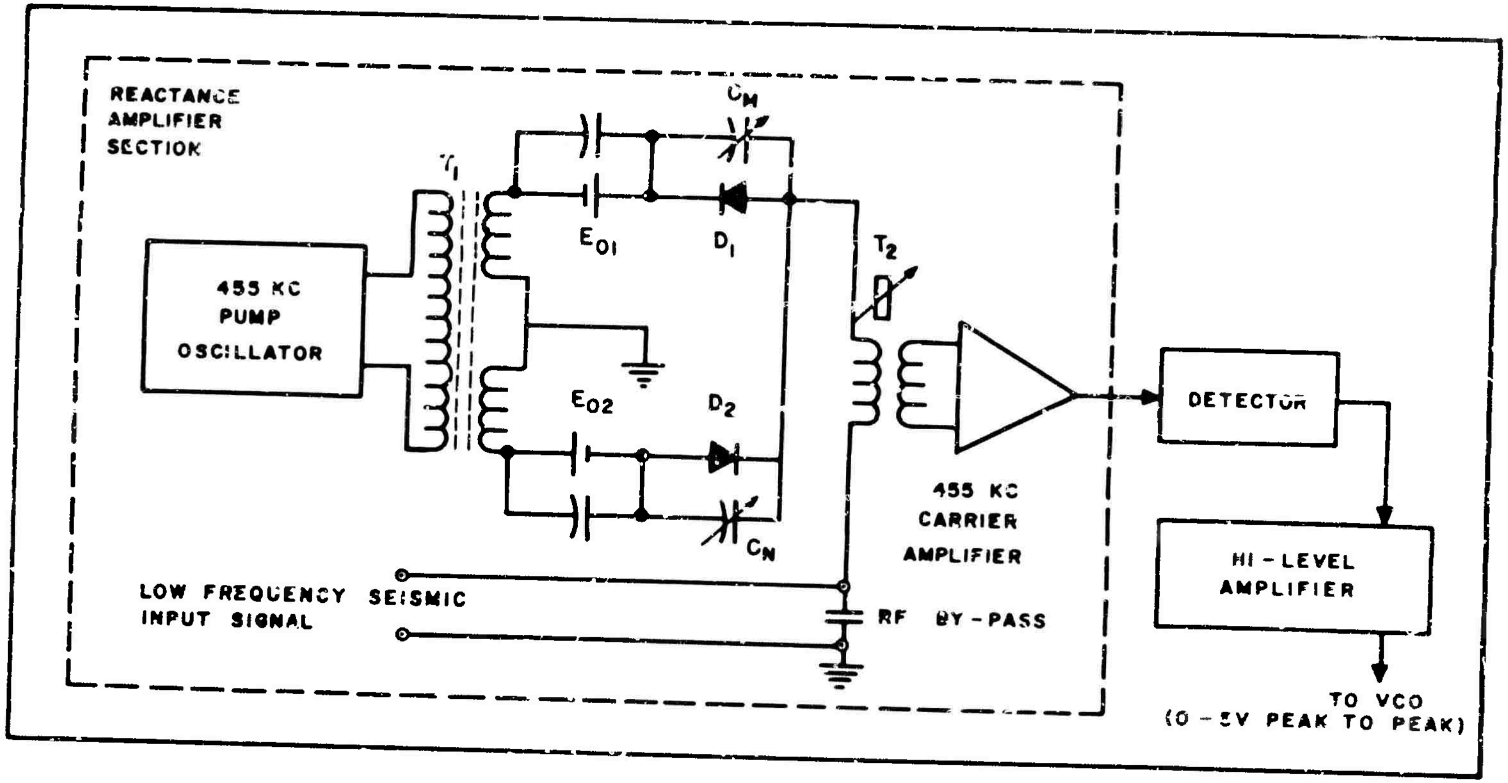
EV 17 RESPONSE CURVE

FIGURE - 8

low-frequency reactance amplifier principles, the second section is a 455 kilocycle tuned amplifier, the third section is an amplitude-regulated pump oscillator, and the fourth section is a stable, real-frequency amplifier.

The reactance amplifier is a double-sideband, up-converter (or modulator) in which a band of low-frequency signals is used to modulate an RF carrier frequency (Figure 6). The nonlinear element to support modulation is the junction capacitance of the reverse biased "varicap" diode.

Pump voltage is applied to the primary of the pump transformer and swings both diodes through their capacity vs. voltage characteristics. The polarized diodes are biased in such a direction that pump voltage causes both diodes to swing in unison up and down their characteristic curve. Thus, if the diodes are matched for identical voltage vs. capacity characteristics, the capacity of one leg at any instant during the pump cycle equals that of the other leg, the bridge remains in balance throughout the cycle and no pump voltage is passed. In practice, one or both of the diodes are paralleled with a trimmer capacitor to permit a controlled unbalance of the bridge. This provides a constant amplitude carrier voltage output which has the proper phase to serve as an AM carrier for the two sidebands resulting from the application of signal voltage to the varicap diodes.



SEISMIC AMPLIFIER CIRCUIT DIAGRAM

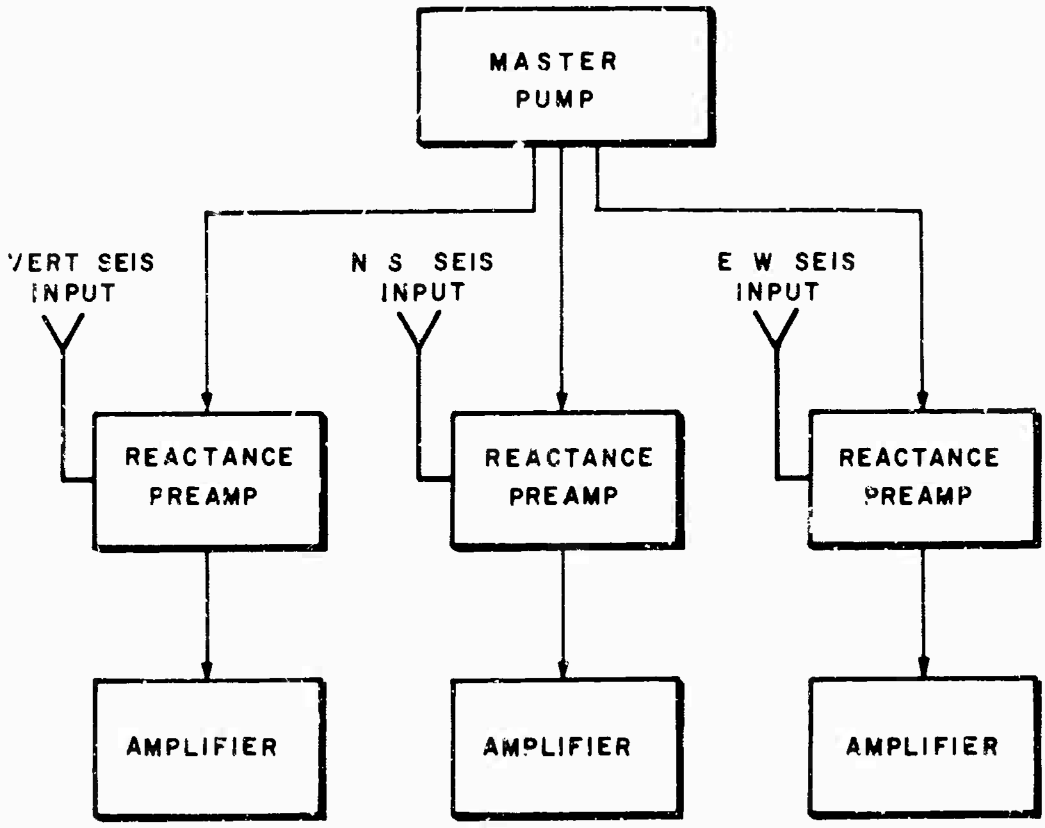
FIGURE - 6

Signal voltage is applied to the "varicaps through the low impedance primary winding of an I-F transformer. It reacts with the time varying capacity of the "varicap" diodes to produce amplitude modulated 455 KC currents. These currents flow through the primary winding of T2 to produce a 455 KC carrier that is amplitude modulated at signal frequency. This signal is amplified in a conventional tuned amplifier and is then detected.

The amplifier section of the transmitter is shown in the block diagram (Figure 7). The system is composed of master pump (oscillator), four reactance preamplifiers, and four, real-frequency amplifiers.

a. Master Pump

The master pump is a 455 KC oscillator which supplies pump voltages to all three reactance preamplifiers in the system. Long term amplitude stability is essential for gain stability of the reactance preamplifier section. Short term amplitude stability is necessary to insure that extra noise is not injected into the system from the pump. This design achieves amplitude stability by diode clipping of both positive and negative peaks of the pump signal.



BLOCK DIAGRAM, AMPLIFIER SECTION

FIGURE - 7

b. Reactance Preamplifiers

The preamplifiers used are solid state reactance (or parametric) amplifiers. Their inherent high input impedance (greater than 15 megohms at 1 cps) makes them ideal for use with high impedance transducers. The preamplifiers' small size, insensitivity to orientation, low noise level and low power level are also important. The equivalent input noise level is less than .05 microvolts rms over the bandpass from 0.8 to 10 cps. The reactance amplifier section is followed by a tuned amplifier detector section. The tuned amplifier requires little power and uses no IF transformers. Tuning is accomplished by small fixed tuned "transfilters" which are antiresonant at the pump (carrier) frequency. These elements, used in the emitter circuits of the two amplifier stages, provide emitter degeneration for all frequencies outside their passband. A high degree local negative feedback is employed in both stages to stabilize the gain against changes in transistor parameters. The first stage is optimized for low noise performance. The preamplifier has an adjustable gain nominally set to 2000 (66 db).

c. High Gain Amplifier

The output of the reactance amplifier is fed into

a real-frequency amplifier having a fixed gain of approximately 10 db. This amplifier requires only two voltage inputs (± 12 volts). The amplifier employs heavy negative feedback to obtain good stability. The open loop gain of the amplifier is approximately 70 db, and is designed with both high and low cutoff filtering.

3. Calibrate Circuit

The calibrate circuit consists of a current source, whose output is controlled by a relay. The amplitude of the calibrate signal is controlled by a 0-60 db attenuator calibrated in milli-microns of earth motion in 6 db steps. Seismometers with or without a separate calibrate coil may be utilized and calibrated. The dial calibrations are based on the motor constants of the EV17 seismometer.

4. Voltage Controlled Oscillator

The voltage controlled oscillator used in this system are manufactured by Electro-Mechanical Research, Inc. They are described by EMR Model No. 307A, are miniature in size, and completely solid state. Three adjustments are provided on the unit, CENTER FREQUENCY, OUTPUT AMPLITUDE, and DEVIATION SENSITIVITY. (See Jobbers Manual)

5. Mixer Amplifier

The outputs of the VCO's are multiplexed through a

high impedance mixing circuit and amplified through an audio frequency bandpass amplifier.

6. FM Transmitter and Receiver

The FM Transmitter/Receiver is made from the Motorola Model H23DEH FM radio, which has been modified in the following manner:

1. The transmitter and receiver sections are separated chassis.

2. The transmitter chassis also includes:

    a. An input potentiometer which controls the modulation.

    b. An ON - OFF switch

3. The receiver chassis also includes:

    a. An ON - OFF switch and pilot light.

    b. RADIO - LAND line switch and cascade emitter-follower. The emitter-follower is used to isolate the discriminator or land line output from the sub-carrier discriminator inputs.

7. Antenna System

The Antenna System utilized for transmission and reception are identical two meter beam units incorporating six elements for over 10 db gain. Mechanically the units are very light, (2 lbs.) and easily set up.

8. Discriminators

The discriminators used in this system are manufactured by Electro-Mechanical Research, Inc. They are

described by EMR Model No. 267. These units have been mechanically altered to meet the mounting requirement. No electrical modifications have been made. (See Jobbers Manual)

9. Power Supplies

The prime regulation of the power supplies are the batteries. Each battery voltage is regulated by a Zener controlled pass transistor.

E. OPERATING INSTRUCTIONS

1. Preliminary Instructions

Prior to any turn on operation several requirements should be met to avoid extensive damage.

a. Under no condition should the transmitter unit be turned on without a dummy load or an antenna connected to the antenna jack.

b. Under no condition should either the transmitter or receiver unit be operated without the modular units in place.

Tests on the transmitter - Receiver units have indicated that under ideal conditions a range in excess of 25 miles can be achieved. However, weather and topographic conditions can greatly reduce this figure. Prior knowledge of the above conditions is a necessity to obtain continuing

results throughout a test. Distances greater than or approaching 10 miles should not be attempted or relied upon unless all conditions are known.

If the tests are to be made over a relatively short distance, dead reckoning on antenna placement and direction may suffice. However, if greater distances are to be achieved, a topographic map and an accurate compass are required. Where reception may be "fringe" and "S" meter will prove to be a necessity.

For both transmitter and receiver units, an antenna and mast must be erected and orientated. The antennae should be at least one wave length (two meters) above the ground or vehicle, and guyed to prevent toppling. Six 5' sections of mast are supplied.

The seismometers to be used must be placed and leveled. Experience has dictated that best practice is to bury the seismometers were practical to reduced wind noise.

The vertical seismometer can be leveled by use of the bull's eye level built into it. Two peep holes, one on top for light and one on the front edge show the relative beam position. The beam position cannot be readily field changed. (See Figure 8)

The horizontal seismometers may be leveled by use

of the bull's eye level, and the beam position centered by adjusting the large screw at one end of the instrument by using a nonmagnetic screwdriver. A double view window on the opposite end indicates the relative position of the beam.

Figure 8 shows the position of the seismometer to produce a positive signal from the North or East direction.

2. Operational Procedures

Turn off both power and radio switches prior to connecting the batteries.

a. Transmitter

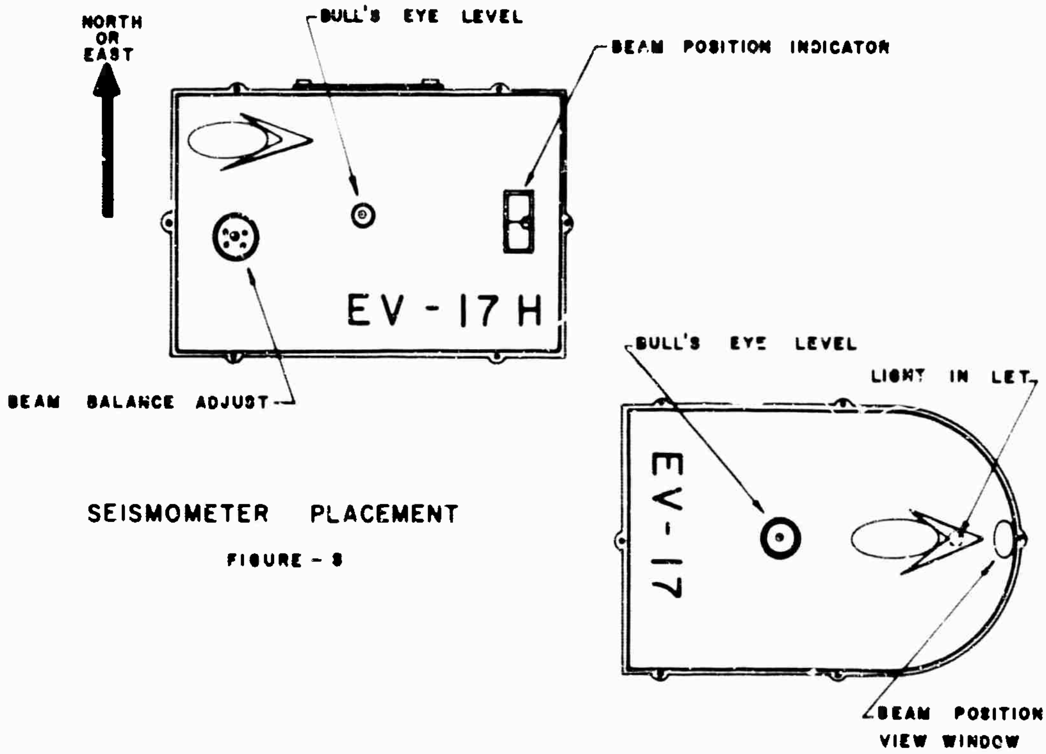
1. Erect and connect antenna

2. Place and connect seismometers to their respective input jacks.

3. Set attenuator to "60 db".

4. Turn main power switch to "ON". This will activate the amplifiers and VCO's.

5. Measure the signal at the amplifier test point on the top panel and adjust gains by means of the step attenuator to approximately 80 mv PP as seen on an oscilloscope using a 10:1 probe. This setting is arbitrary and operator judgment must be employed. Set calibration levels using table II as a guide. This level will deliver approximately a two volt peak pulse to the recorder.



SEISMOMETER PLACEMENT

FIGURE - 8

6. Establish radio contact with the RF RECEIVER unit.

7. Turn transmitter power switch to "ON". When requested, reorientate the antenna for strongest signal.

8. Readjust gain levels as requested and make appropriate cal level changes.

b. Receiver

1. Erect and connect antenna

2. Connect output to recording device. If the PORTABLE SEISMIC SYSTEM is to be used, insure the amplifier input switches are in the "EXTERNAL" position.

3. Stand by for communication from the TRANSMITTER station. When established, talk in the proper antenna orientation for strongest signal.

4. Request any gain changes necessary to give approximately the same level when viewed on an oscilloscope as the Portable Seismic System. Confirm all changes before logging them in.

TABLE II

Gain and Calibration Settings

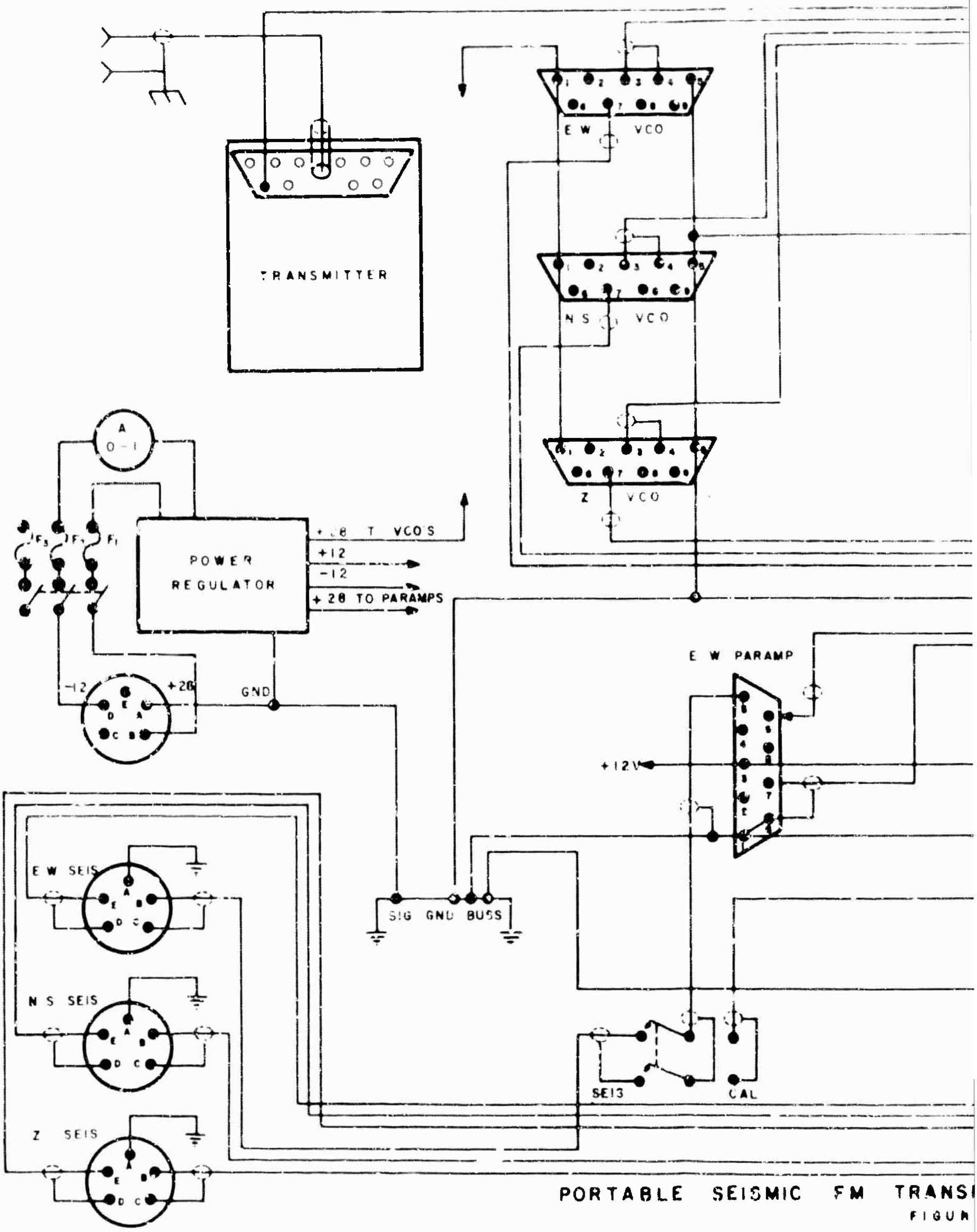
Attenuator Setting (db)	Telemetry System Gain	Overall Gain	*Calibration Setting (mu)
0	15.8K	50K	5
6	7900	25K	10
12	3950	12.5K	20
18	1975	6.25K	40
24	988	3125	80
30	494	1560	160
36	247	780	320
42	123	390	640
48	61	195	1.2K
54	30.5	97.5	2.5K
60	16	48.5	5K

Calibrate settings recommended here will produce a 2 volt pulse at the output of the amplifier in the Portable Seismic System. They will, also, produce a 0.632 volt pulse at the output of the Telemetry discriminator.

*Calibration settings have been increased by a factor of 10.

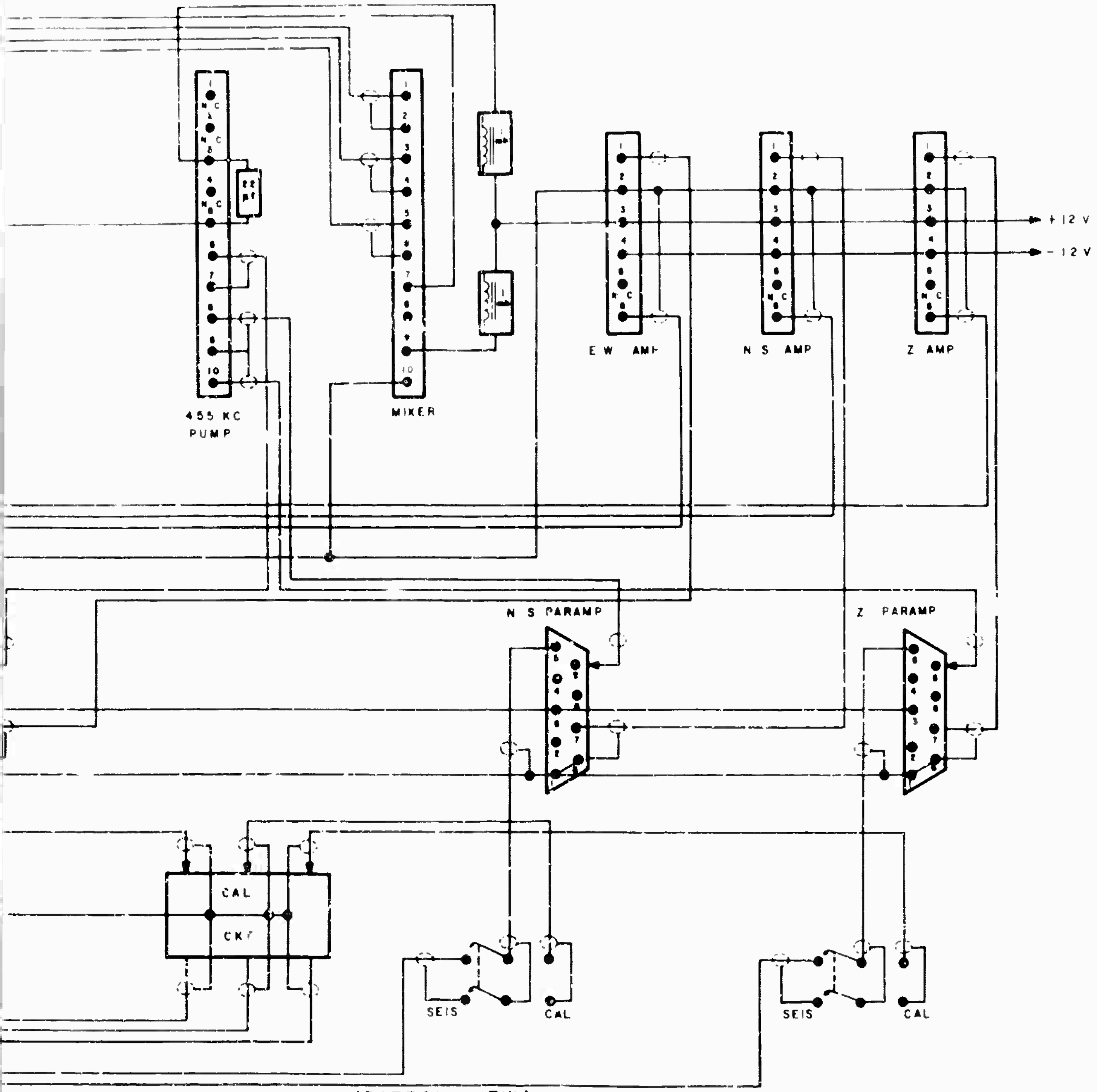
Section II

LIST OF SCHEMATICS & DIAGRAMS

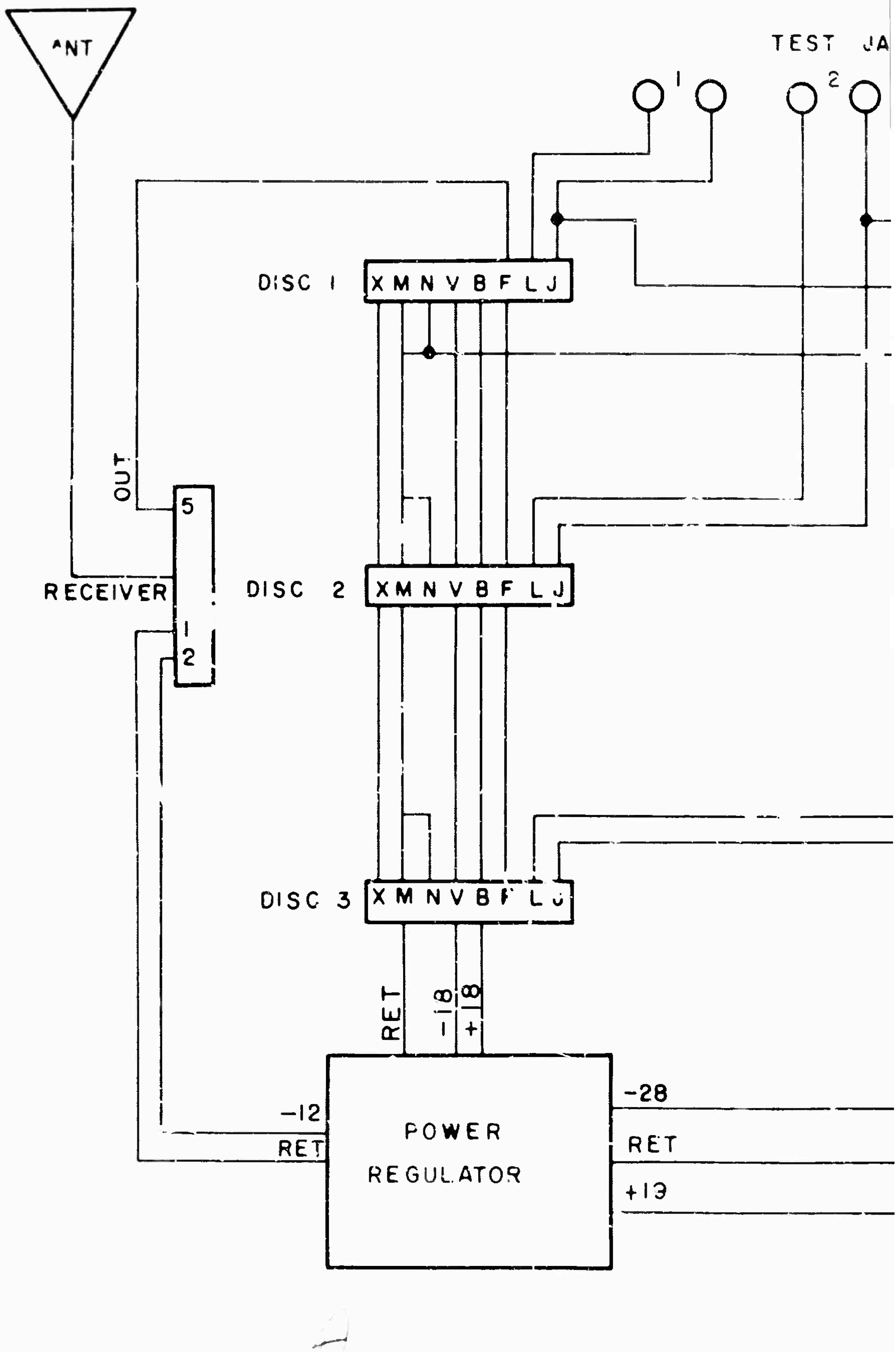


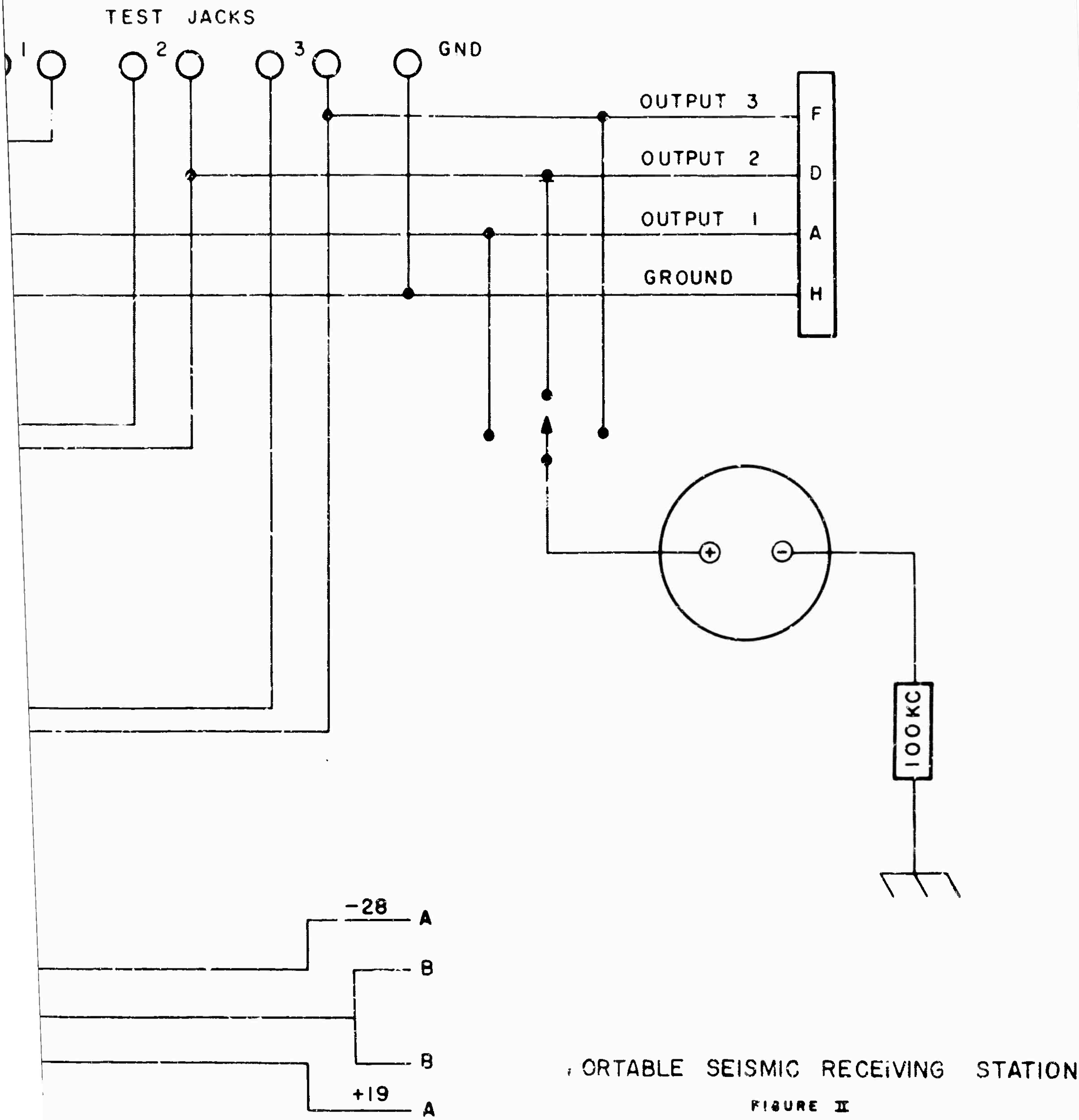
PORTABLE SEISMIC FM TRANS

FIGUR



FM TRANSMITTING STATION (BOTTOM VIEW)
FIGURE I


ANT
TEST JA
1
2
DISC 1
X M N V B F L J
OUT
5
RECEIVER
1
2
DISC 2
X M N V B F L J
DISC 3
X M N V B F L J
RET
-18
+18
-12
RET
POWER
REGULATOR
-28
RET
+13

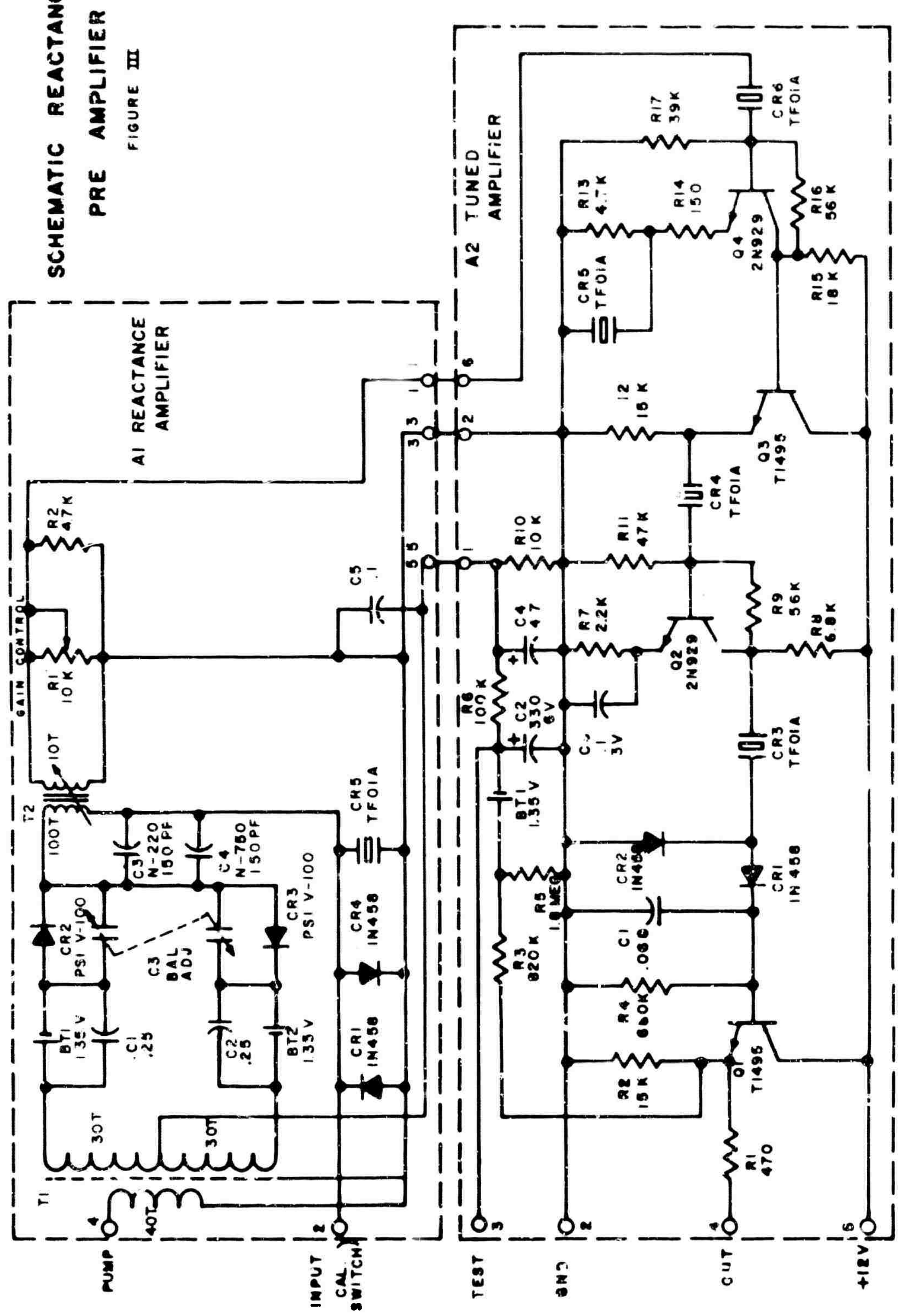


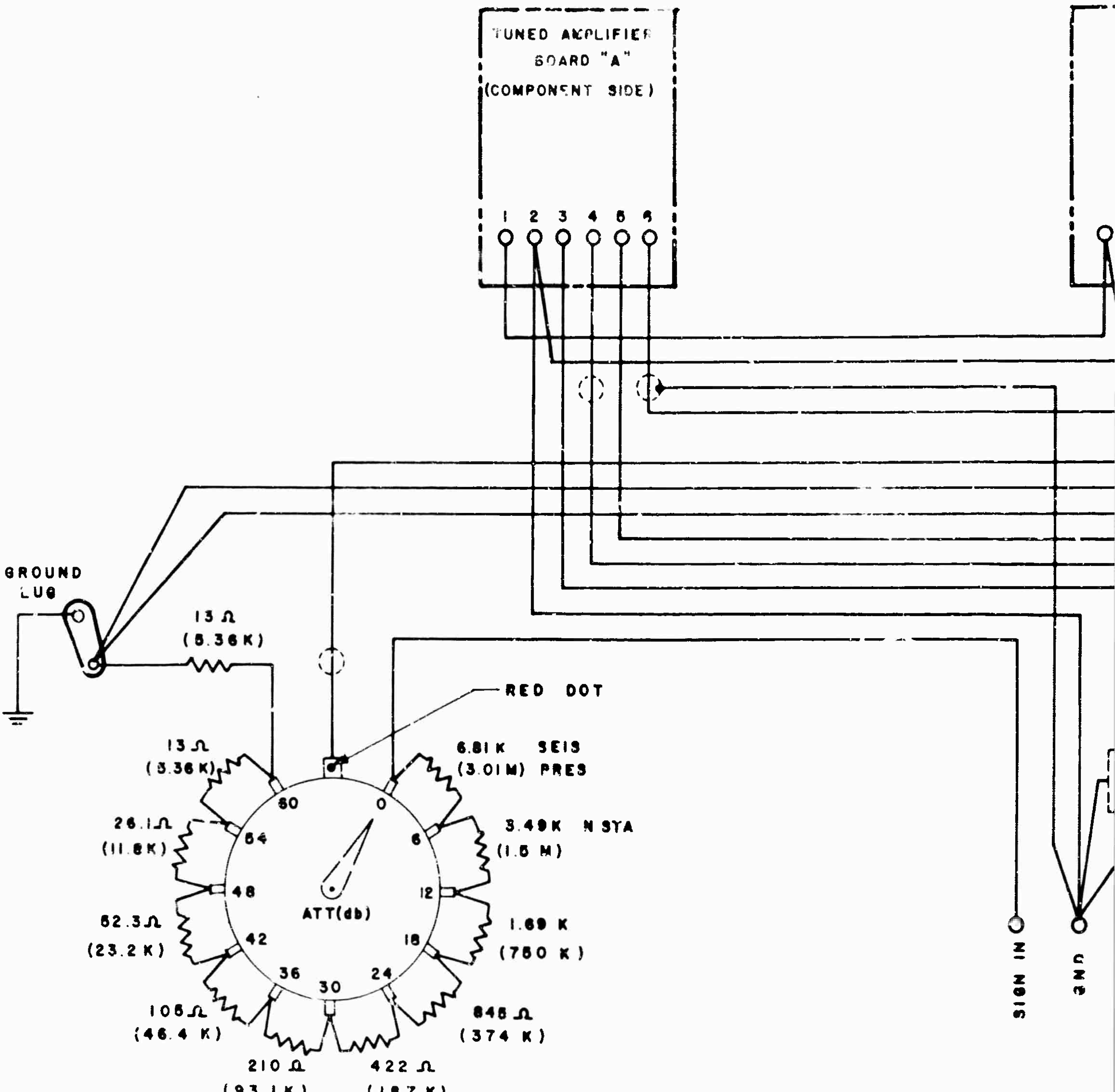
ORTABLE SEISMIC RECEIVING STATION

FIGURE II

SCHEMATIC REACTANCE PRE AMPLIFIER

FIGURE III

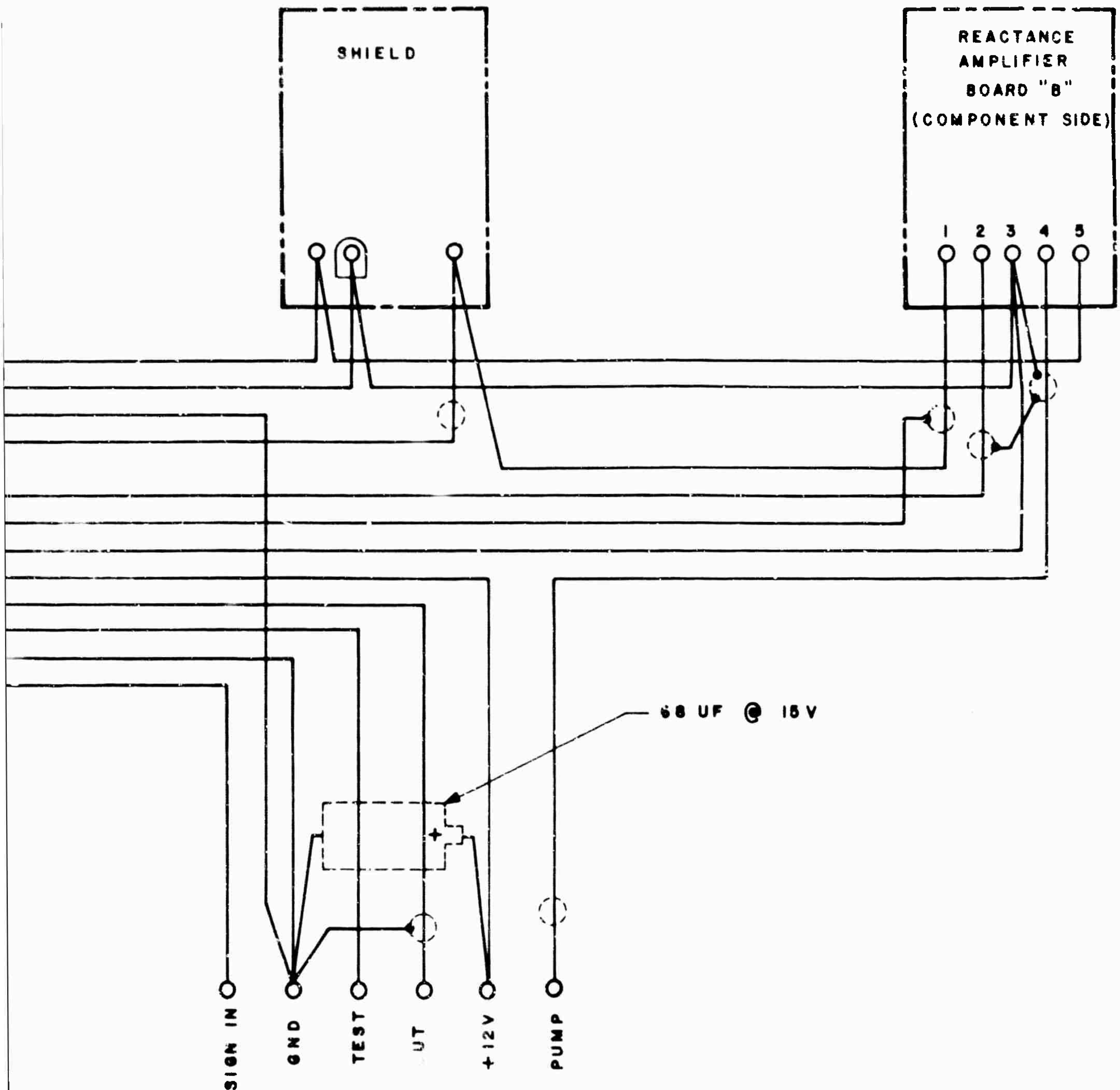




ATTENUATION SWITCH
(FRONT VIEW)

WIRING DIAGR
REACTAN
FIGUR

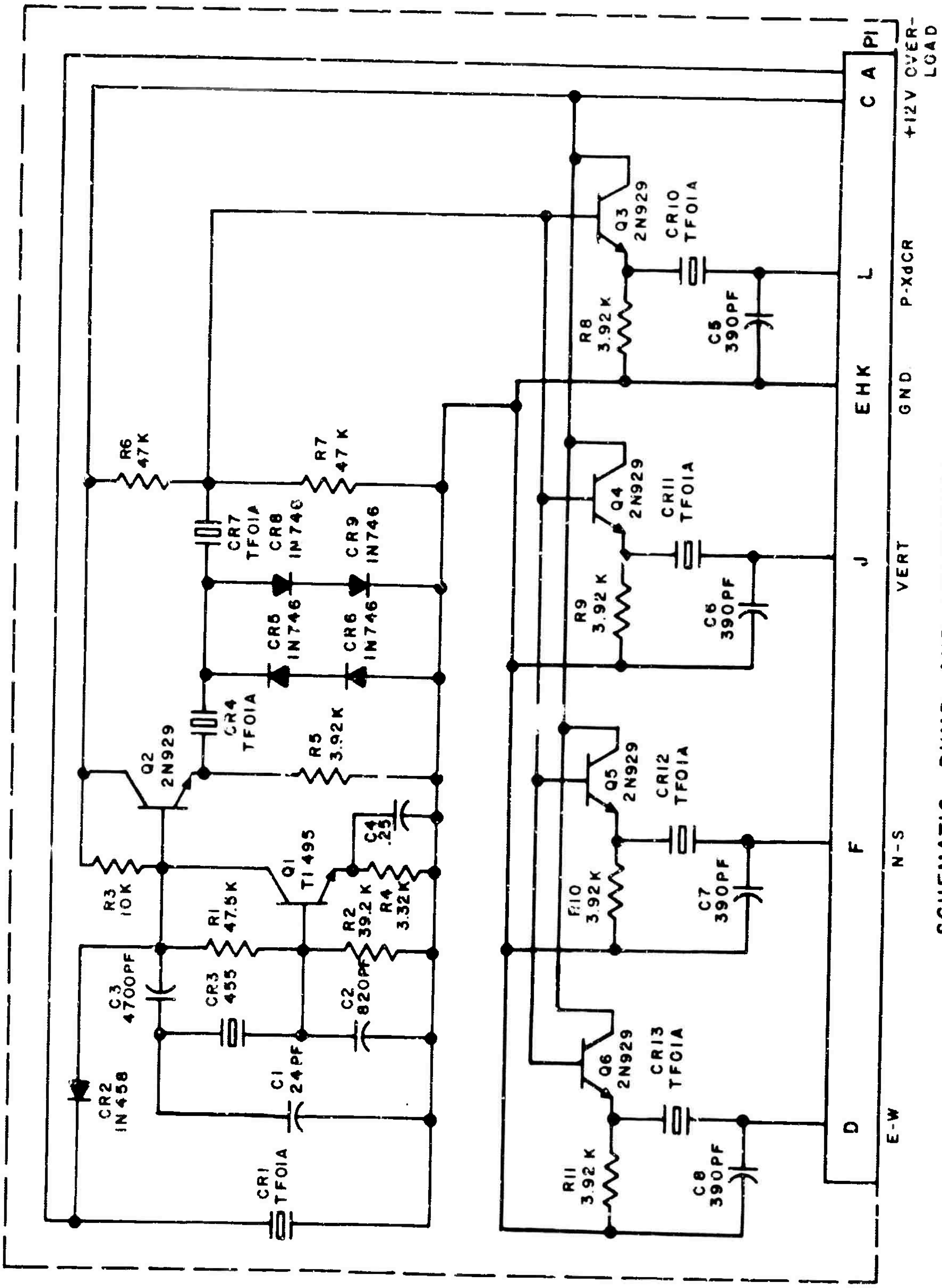
A



WIRING DIAGRAM, INTERNAL, REACTANCE AMPLIFIER

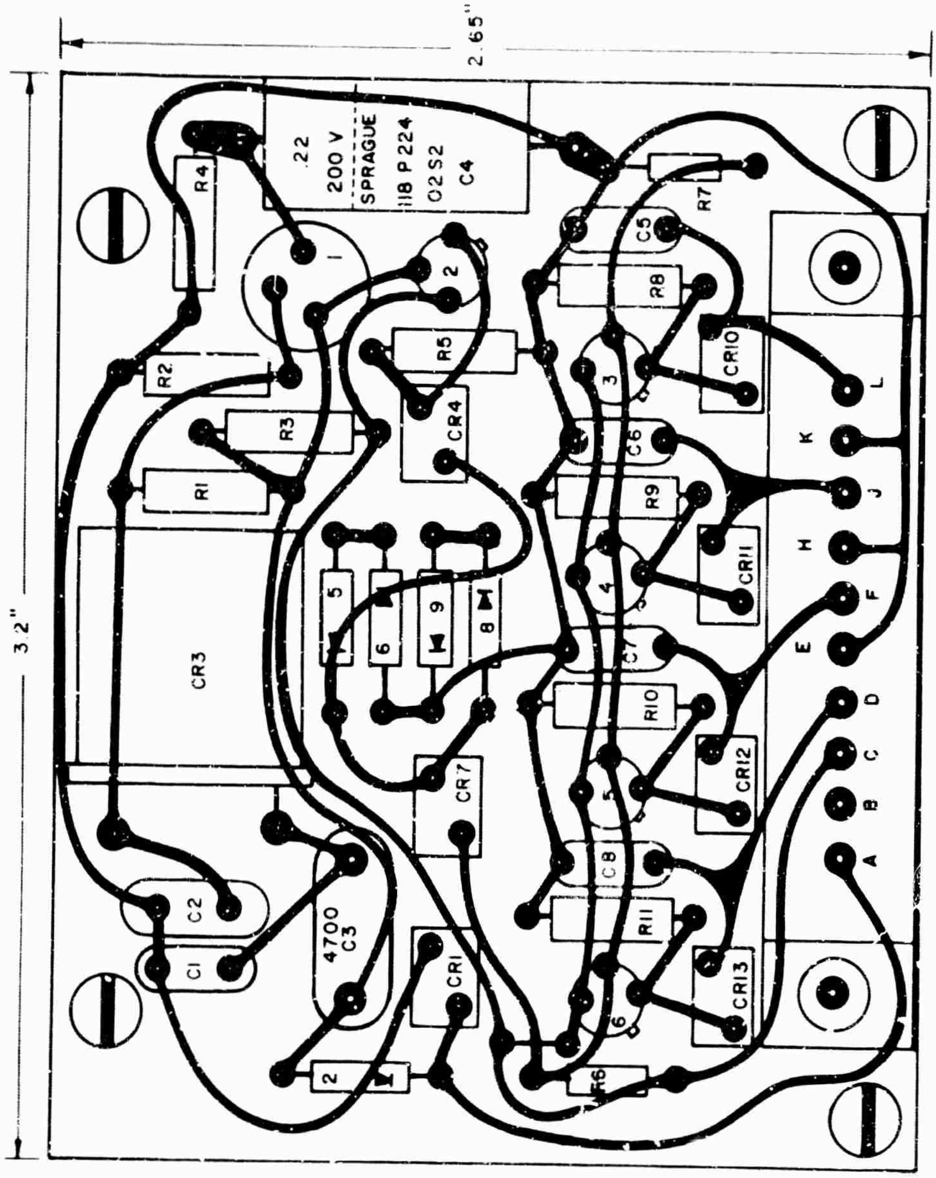
FIGURE – IV

B



SCHEMATIC PUMP AND DISTRIBUTION

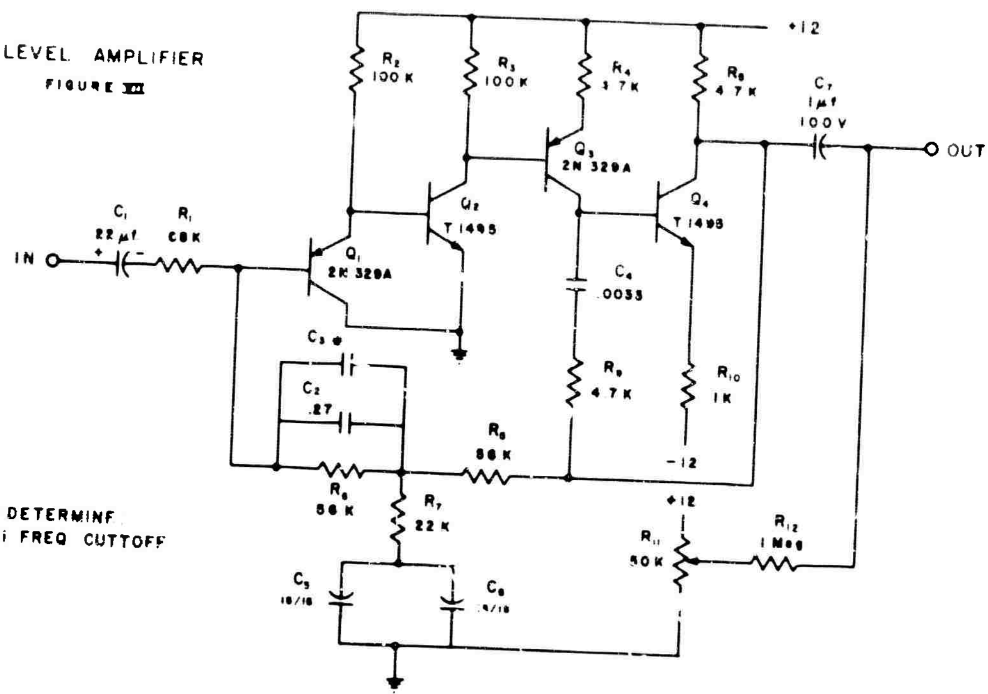
FIGURE V



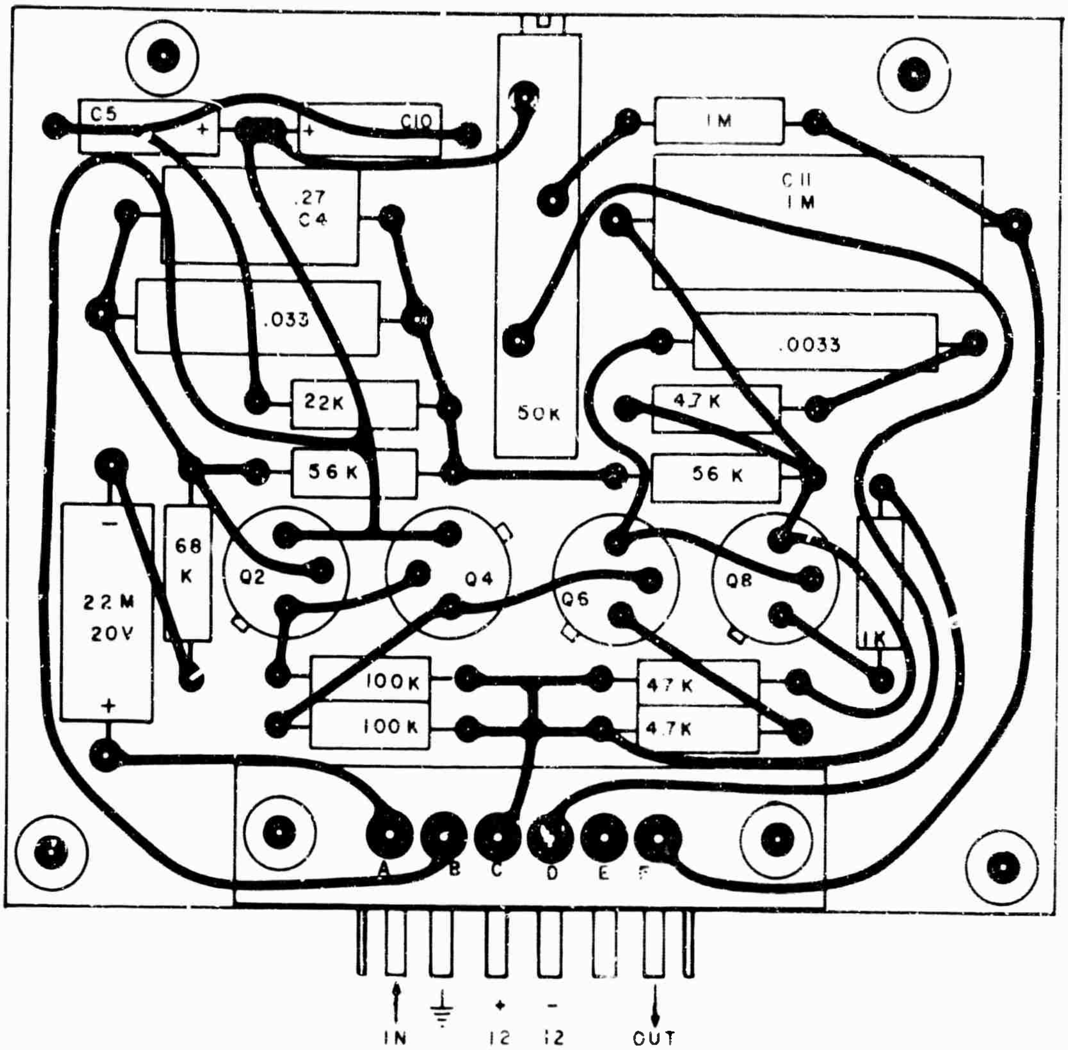
WESTON PUMP AND DISTRIBUTION
FIGURE XI

LOW LEVEL AMPLIFIER

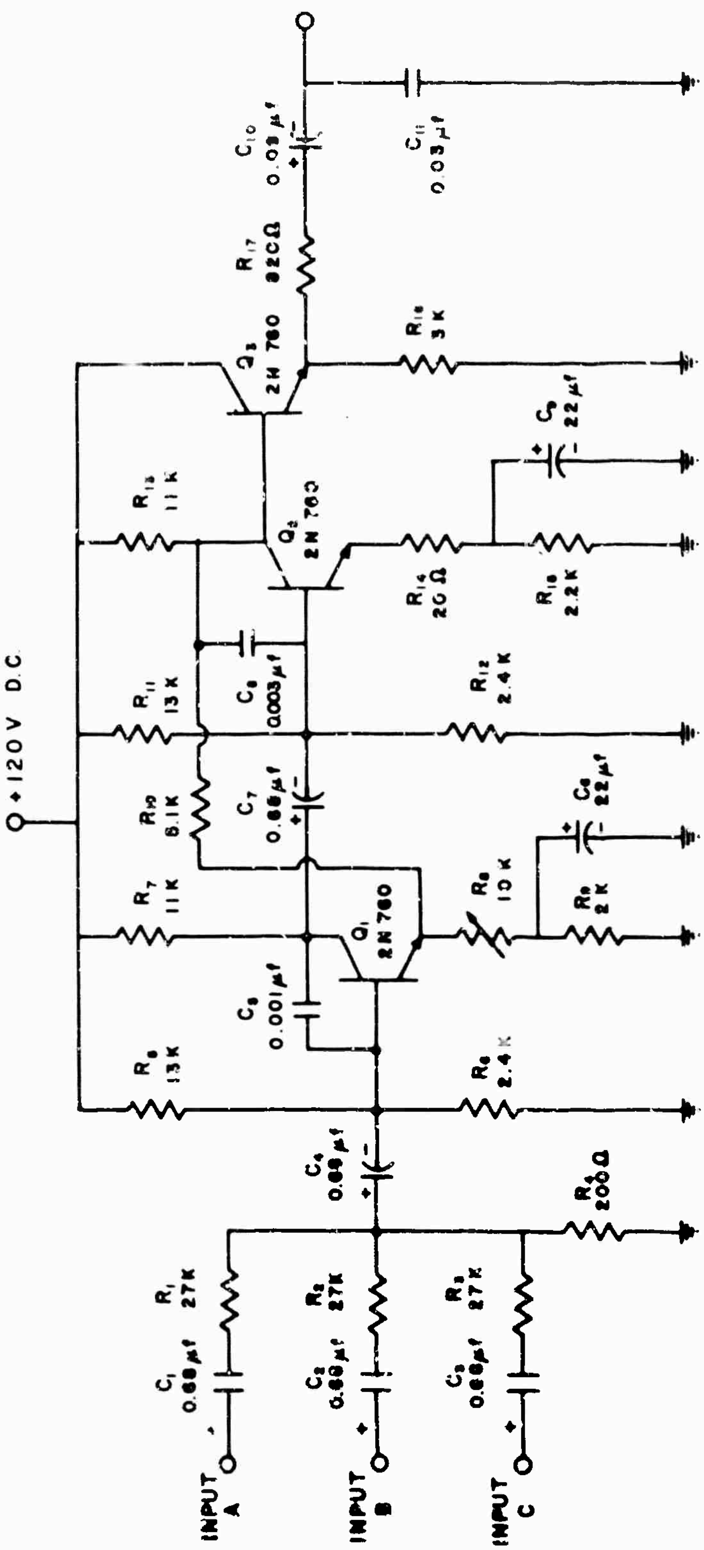
FIGURE III



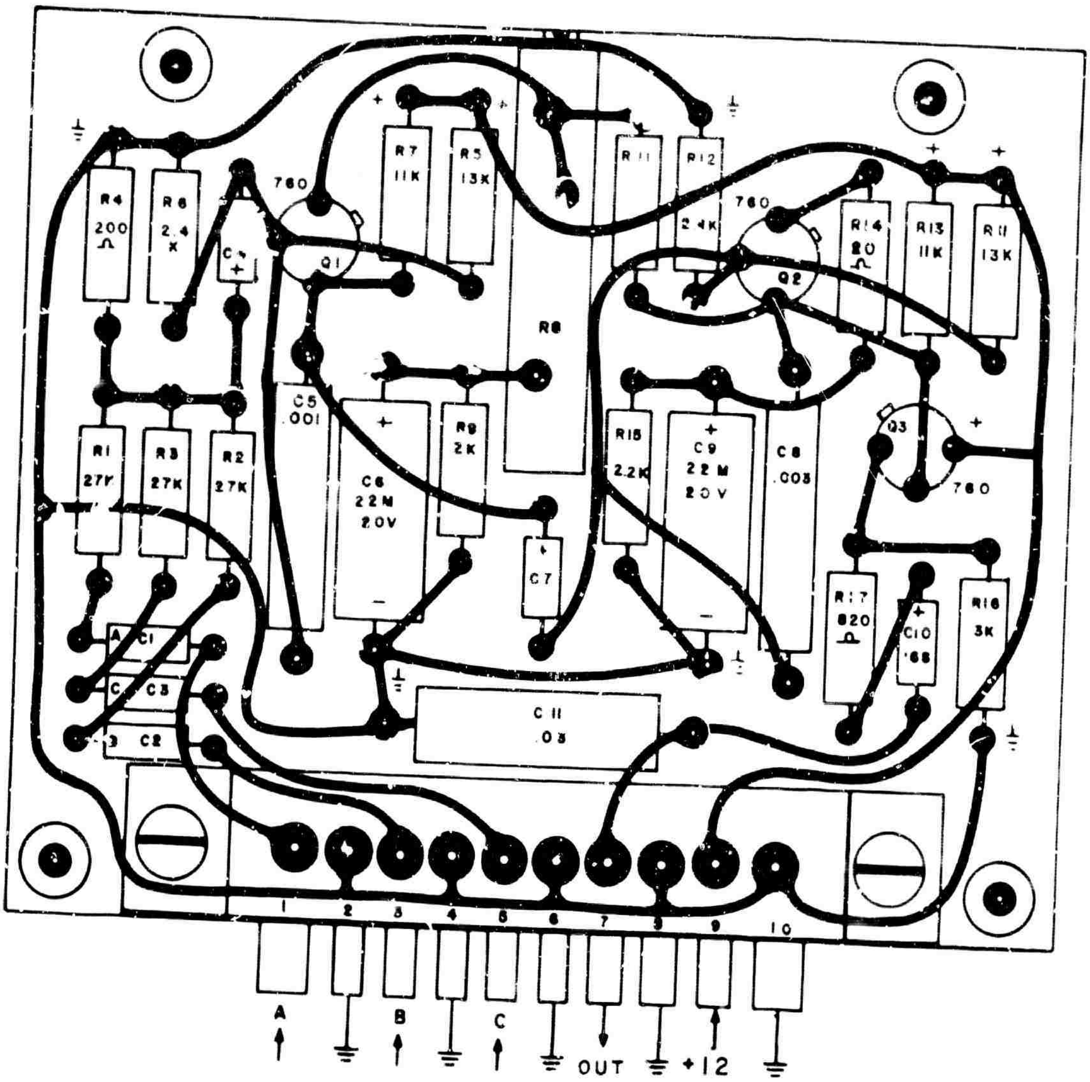
* DETERMINE
HI FREQ CUTTOFF



WESTON LOW LEVEL AMPLIFIER
(COMPONENT SIDE)
FIGURE VIII



A.C. AMPLIFIER AND MIXER
FIGURE IX



MIXER AND A.C AMPLIFIER DIAGRAM

FIGURE X

Section III

SEISMOMETER TEST PROCEDURE

In a previous report (Devane, et al, 1966) a seismometer test system was described. In the course of the present contract, the equipment necessary to carry out the testing has been installed. The testing scheme is illustrated in Figure 1. The BS601 is a fixed program device. In the "Dynamic Average A & B" mode, the computer generates a 5 microsecond pulse at preset intervals. This pulse is amplified and triggers the pulse generator which produces a 20 millisecond pulse of 50 volts. This pulse is conveyed to the test pier and applied through a dividing network to the calibration coil of the seismometer. It is also returned to the BS601 and recorded on channel B. The amplified seismometer response is recorded on channel A. After the data is transferred to the μ-Linc, the impulse and the impulse response are Fourier transformed; the amplitude and phase are calculated from the real and imaginary parts of the transforms and the output spectrum is divided by the input spectrum to give the magnification curve. Each step in the process will be discussed in some detail and estimates of the accuracy of the process will be made at each step.

1. Determination of the Motor Constant of the Calibration Coil

Standard procedures are used to determine the motor constant of the calibration coil. The response to an impulse in current is matched to the response to a known weight removed from the seismometer mass.

Then: $$G_{cc} = \frac{(9.8 \times 10^{-3})\ m\ Xi}{I\ Xm}$$

$$G_{cc} = \text{motor constant, } \frac{\text{newtons}}{\text{ampere}}$$

$Xi \Rightarrow$ zero to peak trace amplitude due to current I

$X_m \Rightarrow$ zero to peak trace amplitude due to weight lift

$I \Rightarrow$ dc. current in calibration coil, zero to peak in amperes

$m \Rightarrow$ mass removed

Figure ? illustrates the procedure and instruments employed.

The procedure requires that the deflections produced by the two methods should agree within 10%. A series of test runs were made on days of low and high microseismic activity. On a very quiet day a series of impulses agree within 3%. But on a noisy day the agreement is only within

13%. Testing should be restricted to those times when the background level is low.

2. <u>Bay State 601 Dynamic Averaging</u>

The seismometer must be operational during the testing process. This means that it will be responding to microseismic activity. The test procedure must separate the calibration signal from the background noise. In conventional testing a weight is usually removed from the seismometer mass and the weight is chosen to produce a response well above the noise level. The Bay State Analyzer permits the use of a very small impulse. It produces an impulse in a coherent manner and conducts a repeated summation of the resulting response. This effectively improves the signal-to-noise ratio by the square root of the number of times that the experiment is repeated, since the incoherent background does not become reinforced while the calibration response does. The repetition rate of the impulse can be chosen in such a way that one insures incoherence between the impulse and the microseismic period predominant at the time of testing. A pulse counter totals the number of times the pulse is repeated. Both the impulse and the impulse response are displayed on the oscilloscope and the operator regulates the output gain to prevent overflow.

To illustrate the signal to noise improvement compare figures 3 and 4. In figure 3, curve II is the sum of 10 impulse responses and curve I is the sum of 20 impulse responses. The signal-to-noise improvement is readily observed.

3. The Impulse Response

The 5 microsecond pulse generated by the Bay State 601 is amplified and fed to a pulse generator. Experiments have shown that the most efficient pulse is one 20 milliseconds long. This pulse is sent over lines to the test pier at 50 volts, because a low level voltage pulse became slightly distorted in the transmission. On the test pier the pulse is fed to a voltage divider so that the input current to the calibration coil may be regulated over a broad range.

An Astrodata Nanovolt Amplifier Model 201 brings the seismometer response to approximately one volt and the signal is returned to the Data Analysis Center. Because of possible 60 cycle pickup in transmission a filter with bandpass .02 to 13.5 cps is used. The impulse response is finally digitized and displayed on Channel A of the Bay State 601.

The Sample Rate Control determines the digitization interval. The highest sampling rate corresponds to digitization period of exactly 5.030 milliseconds or about 198.8 samples per second. Lower sampling rates are expanded in factors of two.

The highest sampling rate gives the largest frequency range in the Fourier Transform, so it is ordinarily used. Lower digitization rates may be used to explore frequency ranges in more detail.

4. <u>Data Transfer - BS601 to Linc</u>

A subroutine in a multi-routine program called WEST A transfers the data in the BS601 output memory to the Linc. The 503 data points are transferred to two blocks of Linc tape. Each block of Linc tape contains 256 words; thus, there are nine words which must be treated as nonsense words as far as the data is concerned. To prepare the transferred data for the Fourier Transform program, short program labeled "CONDENSE" has been written. It must be noted that both the impulse and the impulse response are stored by the BS601 and displayed on the oscilloscope. In this display and consequently in the BS601 output memory, the two functions are interlaced, i.e. even numbered data points belong to the impulse response; odd to the impulse. "CONDENSE" separates the two functions and stores them on separate blocks of tape. Note that the impulse response is reduced to a 256 point function and that the digitization interval becomes 10.06 milliseconds.

The BS601 Output Gain Control enables the operator

to select any contiguous group of eight bits from the nineteen bit output of the Analyzer. The most significant bit, (the sign, 20th bit) is not affected by this control. When the output gain is at 1 the eight most significant bits are selected; when set at 2048, the least significant bits are selected, and the gain is effectively 2048 times the gain at a setting of 1. There are 12 output gain settings and the effect of the 8 bit selector on accuracy of the number transferred must be considered. Table II is an attempt to set guide lines for the use of the Output Gain Control.

Column 1 lists the powers of 2; column 2, the sum of successive powers. The maximum number which can be transferred is 510, the eight bit number 11 111 111. Column 3 gives the output gain control values as marked on the Analyzer. Column 4 is the multiplier suggested for each gain control setting. Column 5 is the product of the multiplier and the maximum value of the 8 bit number (510). Comparison of column 2 and 5 shows the growth of the roundoff error.

For example, the number 160 appears as the maximum value of the impulse response after a transfer at 16. To recover the original value we multiply by 128 hence, 20480. But the possibility exists that the number may actually have been 20608. This amounts to an error of less than 1%.

Care must be exercised when dealing with small numbers.

If 100 is transferred at	2048	100	x	1	=	100
	1024	50	x	2	=	100
	512	24	x	4	=	96
	256	12	x	8	=	96
	128	6	x	16	=	96
	64	2	x	32	=	64

As a rule the maximum output gain control setting short of overflow is recommended.

The output of the seismometer transducer is a voltage. The voltage is digitized by the BS601. Hence, we need a calibration curve which relates the BS601 number to voltage. A curve was constructed by allowing the BS601 to digitize the output of a square wave generator. The voltage was measured by a calibrated digital voltmeter. Several trials produced varing results. The reason for the changes is the input A control, which adjusts the sensitivity of the operational amplifier used to condition the analog input signal for application to the channel A analog-to-digital converter. The control has a vernier gain adjustment with a range of approximately 3:1. Thus, a one volt signal applied to channel A input may result in a number between 88 and 255.

In a series of tests the vernier control should be kept at the same level to avoid necessity of multiple calibration.

5. The Fourier Transform Program - XFORM

The XFORM program is intended for operating on 511 point functions. The routines used are floating point operations with four bit exponents and twenty bit mantissas. The impulse response function presented to the program has 0 in the first 255 locations followed by the 256 actual data points which make up the impulse response. This permits us to consider the response as zero until the instant the seismometer begins to respond to the impulse.

The XFORM program uses Simpson's Rule (m = 2) of numerical integration to compute $P(f) = \int_{-\infty}^{+\infty} C(T) e^{-2\pi ift} dt$. The integration becomes a summation over 511 terms with differential increments Δf and Δt being the distances between points representing the functions P(f) and C(t) respectively.

A full range two-sided transform starts at $f = \frac{-1}{8\Delta t}$ and extends to $f = \frac{1}{8\Delta t}$. The full range consists of 511 units or increments. A full range transform of 511 point function is another 511 point function. The real and imaginary parts of the transform are stored in four blocks of Linc tape designated by the operator.

To establish a relationship between a data point and frequency we use the following considerations. The original sweep rate is maximum; therefore, the data points are 5.03 milliseconds apart, but alternate data points represent the impulse and the impulse response are .01006 seconds apart. $8\Delta t$ = .08048 seconds; hence, the frequency range is from -12.425 seconds^{-1} to +12.425 seconds^{-1}. The transform is a 511 point function so the frequency intervals are .04863. Table 1 has been constructed to make rapid conversion from data point to frequency possible.

6. Conversion to Amplitude and Phase

The full range Fourier Transform produces a real and imaginary part. These are combined to give amplitude and phase by:

$$A = \sqrt{R^2 + I^2} \qquad \text{Tan.}\ \phi = \frac{I}{R}$$

The program AMAPH performs this task. The arithmetic routines are in double precision floating point format with a ten bit exponent and a twenty-one bit mantessa. Floating each block of data requires 3 blocks of Linc tape. The complete solution then occupies 12 blocks of tape in floating point format. The program PACK reduces each three block segments to two blocks of data preserving the precision

to four decimal places. Thus, there are four blocks f data with values of the amplitude and four blocks of phase data. This provides the response of the instrument under test in the frequency range -12.425 seconds^{-1} to +12.425 seconds^{-1}. If the transforms are symmetrical, it is possible to reduce the length of the computation by considering only the domain of positive frequency.

To prepare the data for plotting an additional program PREPLOT was written. This simply discards the decimal precision and reduces the amplitude data to one block of data. This has provided more than adequate in handling amplitude data, but the precision in the phase data is lost. To avoid this loss of data it is planned to construct a program which will give the phase in degrees for each increment in frequency. Due to intermittent operation of the computer, the plot routines were not completed in time for this report, so the graphs presented were drafted. There should be little difficulty in completing this phase of the programming. There are still some problems with the program which divides the output spectrum by the input spectrum. Copies of the computer programs are not included in this report because of the specialized nature of the LINC language. The programs are available to anyone interested.

The entire process will now be illustrated by using the Geotech Model 18300.

The Model 18300 is a small, light weight, short period moving-coil seismometer. It weighs less than 25 pounds and has a 5 kilogram mass. The seismometer may be operated in either the horizontal or vertical position and the period is adjustable from 2.1 to .75 seconds. Pertinent data is contained in table III.

The following discussion refers to conditions when the Period Adjust Knob is at position 0.

The free period of the seismometer was measured in two ways. A weight was removed and the oscillations recorded on a rectilinear Esterline Argus recorder with paper speed of 12 inches per minute. The measured period is 1.07 seconds. Then a pulse was applied to the calibration coil by the Bay State 601 and the oscillations recorded on the Analyzer and transferred to the Linc. Since the time interval between data points is known exactly, this method is recommended. The measured period is 1.046 seconds. The open circuit damping is .007. With an external damping resistance of 8505 ohms the damping is nearly critical, 7.8% overshoot.

The calibration coil motor constant is .194 $\frac{\text{newtons}}{\text{ampere}}$.

A lcps peak to peak sinusoidal current of 7.66×10^{-4} amps in the calibration coil theoretically produce an equivalent ground motion of 76 microns. The recorded peak to peak amplitude corresponding to this input is 34 mm. Hence, the magnification at this frequency is 4.47×10^{4}.

The complete magnification curve could be drawn by a repetition of this process at varying frequencies. It has t done here only to check to machine processed magnific curve.

The testing procedure described above was employed. The impulse response shown in figure 4 was Fourier Transformed, the amplitude and phase calculated. The output is shown in figure 7. Figure 8 gives the relative magnification curves for periods .75 seconds and 2.1 seconds derived from the impulse responses shown in figures 5 and 6. Since we begin with one block of data, displacement verses time, we finish with one block of data, amplitude verses frequency. The computer output is shown in table IV. With the aid of table I we can interpret the data. The amplitudes corresponding to frequencies 1...12 are underlined.

As shown, this is not quite the desired result since the program to produce the division by the impulse spectrum is not yet completely debugged. Hence, at present there are

only relative magnification curves available. Comparing the magnification at 1cps, the machine processed data gives a value of 4.21×10^4 compared to the 4.47×10^4 value derived from a sinusoidal input.

The task for the next quarter then must be to define sources of error, the completion of the computer programs so that absolute magnification curves in both amplitude and phase may be derived.

TABLE I

DATA PT.	VALUE IN SEC.$^{-1}$	DATA PT.	f(Sec.$^{-1}$)
1	.04363	28	1.36
2	.09726	29	1.41
3	.1459	30	1.46
4	.1945	31	1.507
5	.243	41	1.994
6	.292	51	2.480
7	.3404	52	2.529
8	.389	62	3.015
9	.437	72	3.501
10	.486	82	3.987
11	.535	83	4.036
12	.584	92	4.472
13	.632	93	4.522
14	.680	102	4.960
15	.729	103	5.009
16	.778	123	5.981
17	.827	143	6.954
18	.875	163	7.926
19	.924	164	7.975
20	.973	165	8.024
21	1.02	185	8.996
22	1.07	205	9.97
23	1.118	215	10.45
24	1.167	235	11.43
25	1.216	236	11.476
26	1.264	237	11.525
27	1.313	247	12.01
		255	12.40

TABLE II

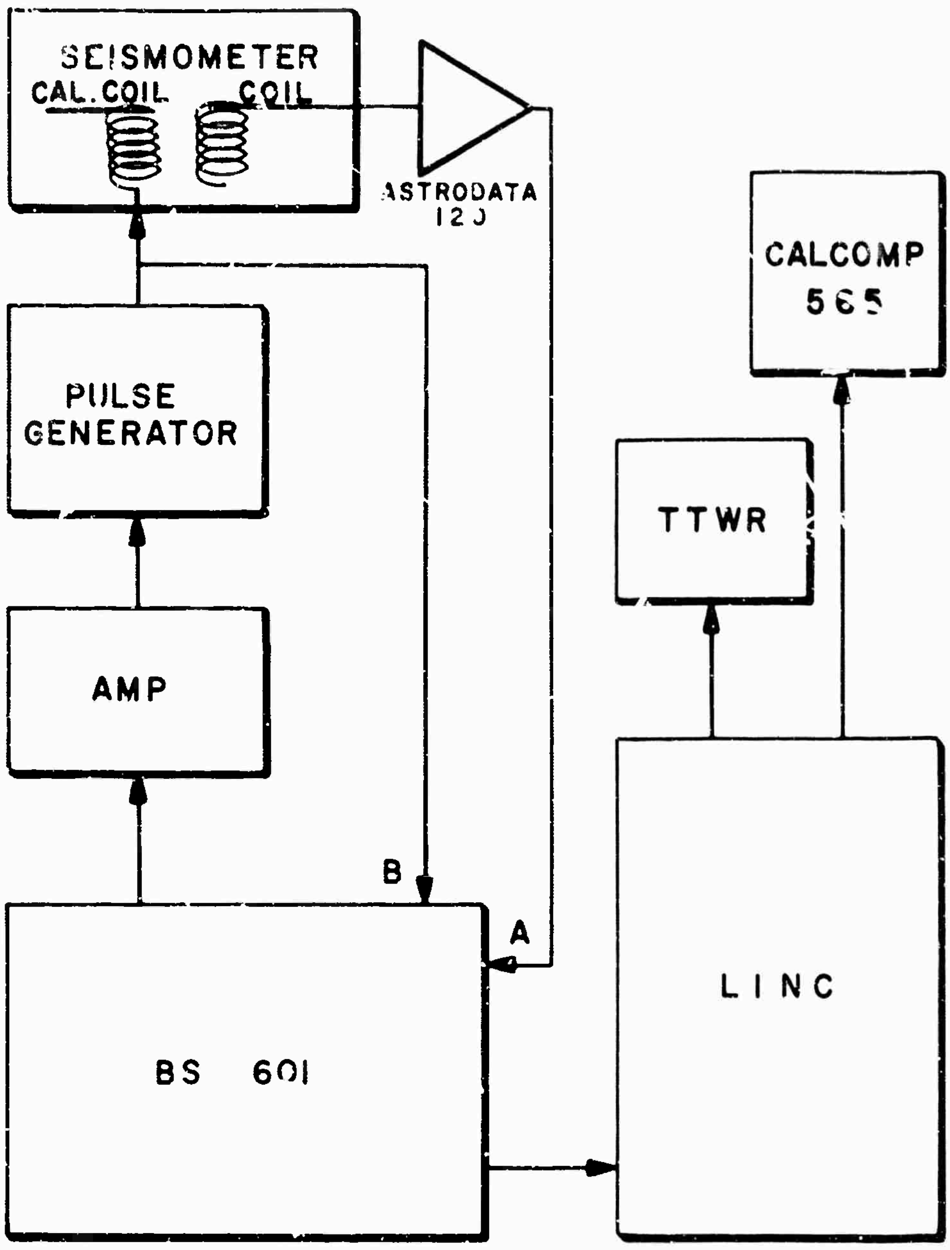
POWER OF 2	$\sum_{1}^{n} 2^n$	OGC	MULTIPLIER	PROD. TRANS.
2	2	2048	1	2
4	6			6
8	14			14
16	30			30
32	62			62
64	126			126
128	254			25[illegible]
256	510	2048	1	510
512	1022	1024	2	1020
1024	2046	512	4	2040
2048	4094	256	8	4080
4096	8190	128	16	8160
8192	16382	64	32	16320
16384	32766	32	64	32640
32768	65534	16	128	65280
65536	131070	8	256	130560
131072	262142	4	512	261120
262144	524286	2	1024	522240
524288	1048574	1	2048	1044480

TABLE III

PER. ADJ. SETTING	PERIOD	CDR X	% OVERSHOOT	G_{cc}
-5	2.10 Sec.	28000	3.6	1.96×10^{-1}
-4	2.05	18000	5	1.96×10^{-1}
-3	1.625	13000	6	1.94
-2	1.25	9515	6	1.95
-1	1.20	8505	8	1.96
0	1.04	8505	7.8	1.96
+1	.95	8505	10.0	1.96
2	.85	8505	10.5	1.92
3	.80	8505	11.4	1.866
4	.775	8505	12.05	1.832
5	.75	8505	12.5	1.824

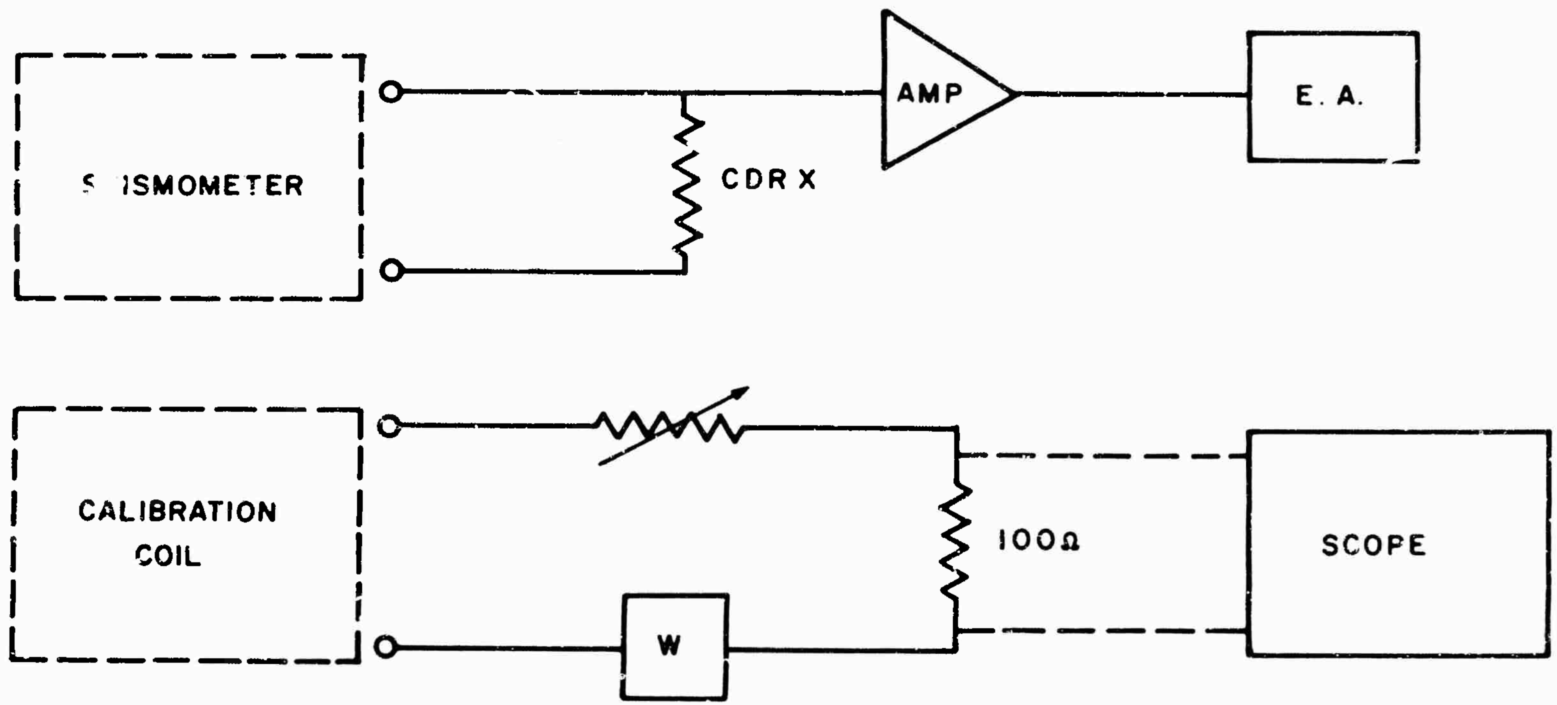
TABLE IV

0000	283	348	424	492	545	581	602	613
0010	617	622	629	638	644	645	637	619
0020	591	558	524	494	473	461	455	449
0030	440	426	406	385	365	350	341	337
0040	335	331	324	313	300	287	277	273
0050	271	273	273	271	265	259	252	246
0060	244	242	242	239	235	229	223	217
0070	214	213	214	216	215	212	207	200
0100	193	187	183	182	181	180	178	176
0110	172	171	171	172	173	173	172	167
0120	162	156	152	151	151	153	154	152
0130	149	143	138	133	131	131	132	133
0140	132	131	127	124	122	121	122	124
0150	124	124	122	118	114	112	111	113
0160	115	118	118	117	114	109	105	103
0170	103	104	106	108	107	106	105	103
0200	101	100	99	99	97	96	93	92
0210	91	90	91	93	94	93	93	93
0220	91	90	89	89	88	88	87	85
0230	83	82	82	82	82	82	82	80
0240	80	78	77	77	78	80	80	80
0250	78	76	75	74	75	77	79	80
0260	80	78	75	70	67	66	65	66
0270	67	68	68	67	65	65	65	67
0300	69	69	69	68	65	63	60	59
0310	60	61	62	64	64	63	60	58
0320	55	54	52	53	53	53	53	52
0330	52	53	53	54	55	56	56	55
0340	55	54	53	52	52	51	51	49
0350	49	47	47	47	47	46	46	45
0360	45	44	43	43	43	43	43	43
0370	41	40	38	37	37	38	39	



SEISMOMETER TEST SYSTEM

FIGURE -1-



EVALUATION OF CALIBRATION COIL MOTOR CONSTANT

E.A.	ESTERLINE ANGUS RECTILINEAR GRAPHIC AMMETER MODEL AW
AMP.	DYMEC MODEL 2460 A
W	WAVETEK FUNCTION GENERATOR
SCOPE	TECTRONIC 564

FIGURE -2-

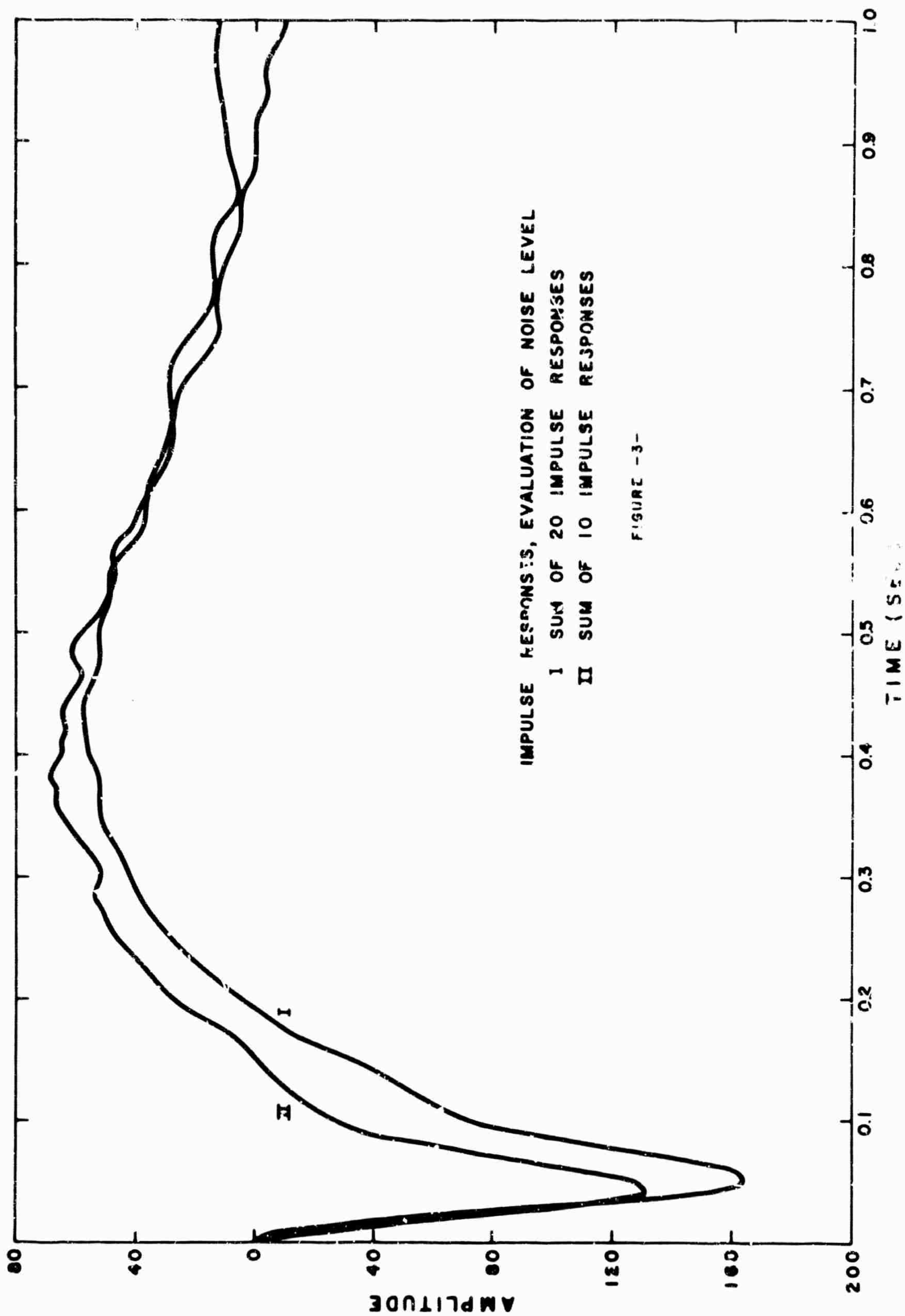
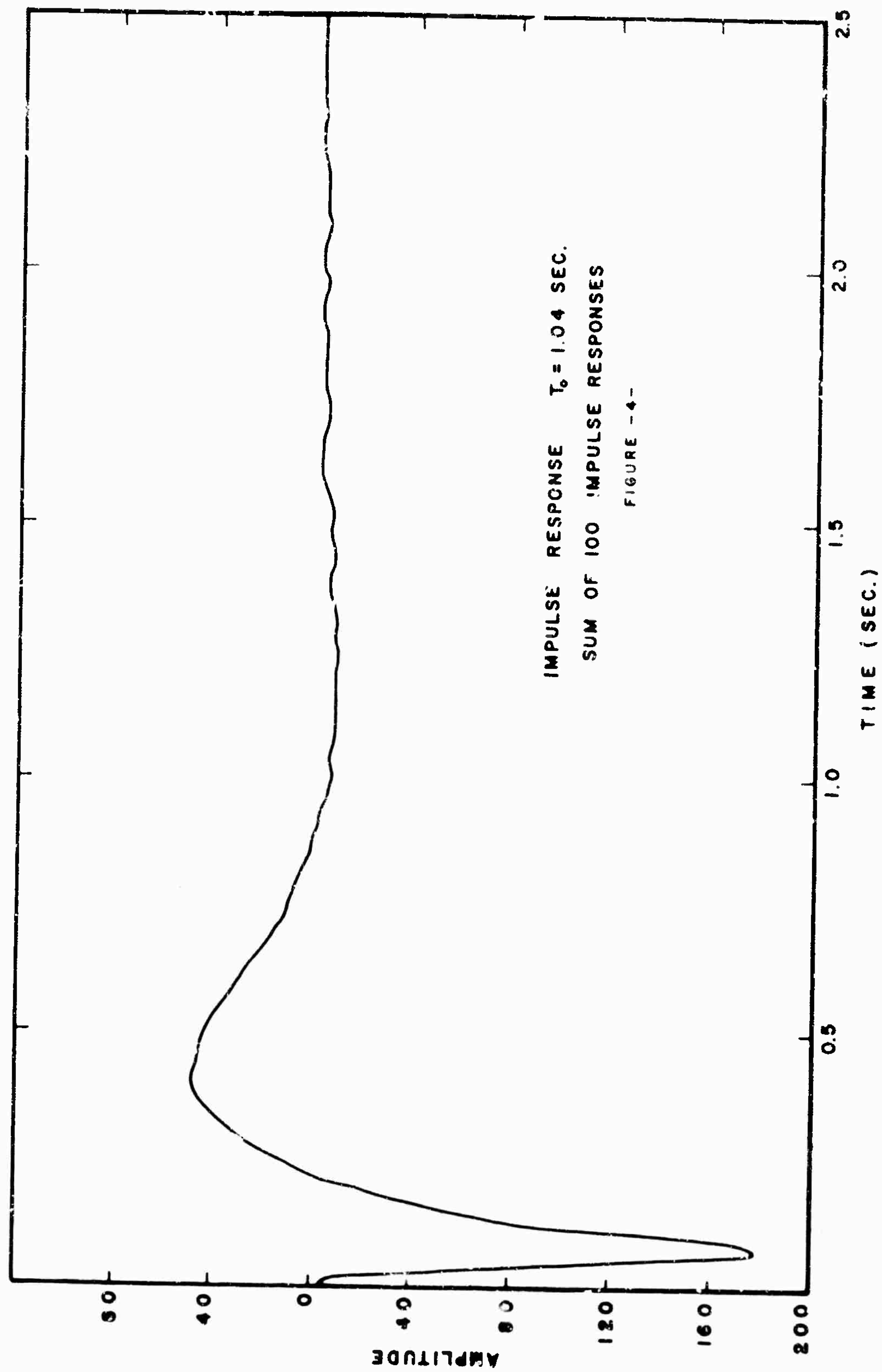
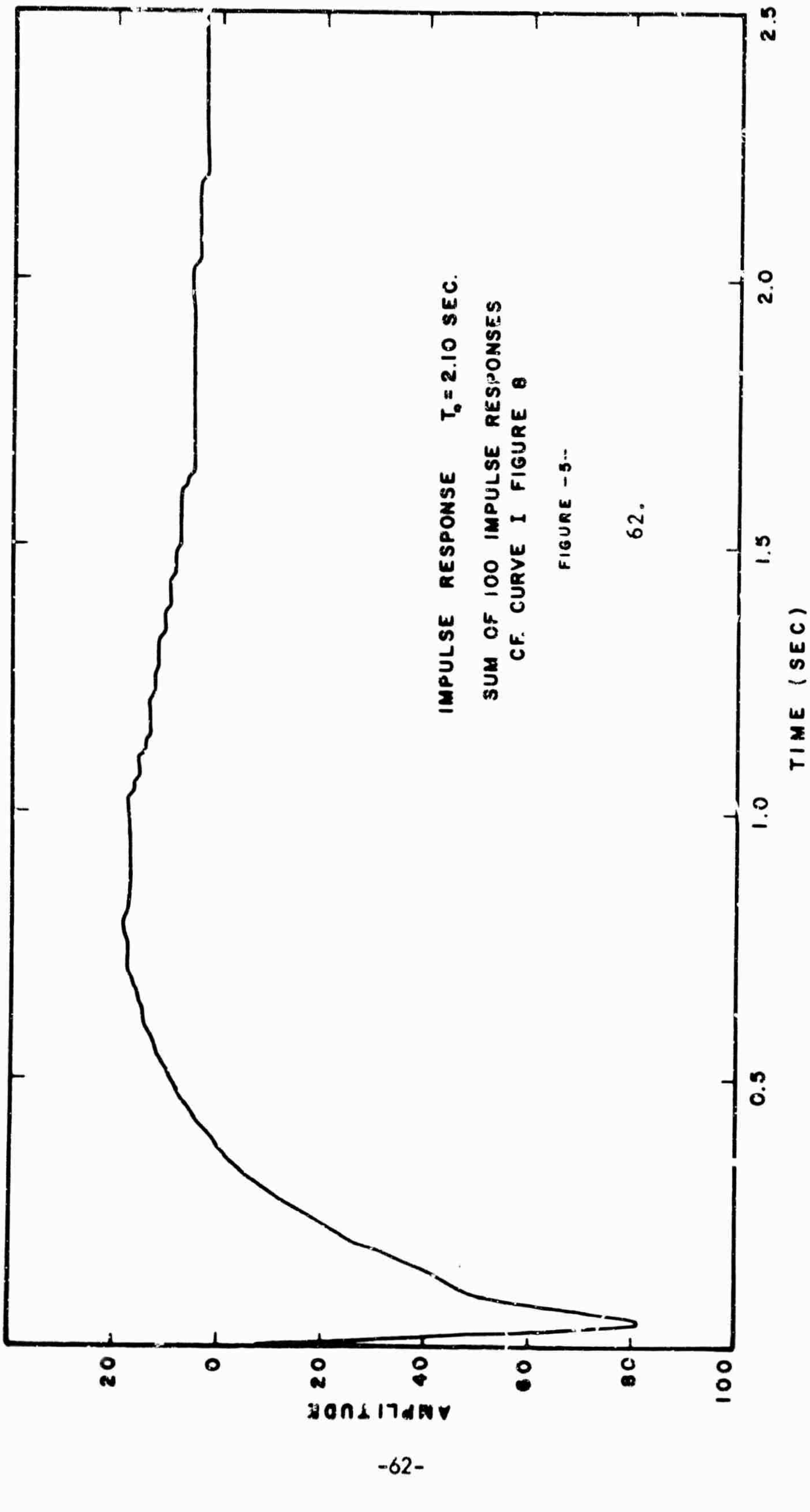

IMPULSE RESPONSES, EVALUATION OF NOISE LEVEL
I SUM OF 20 IMPULSE RESPONSES
II SUM OF 10 IMPULSE RESPONSES
I
II
AMPLITUDE
80
40
0
40
80
120
160
200
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
TIME (SEC)

FIGURE -3-

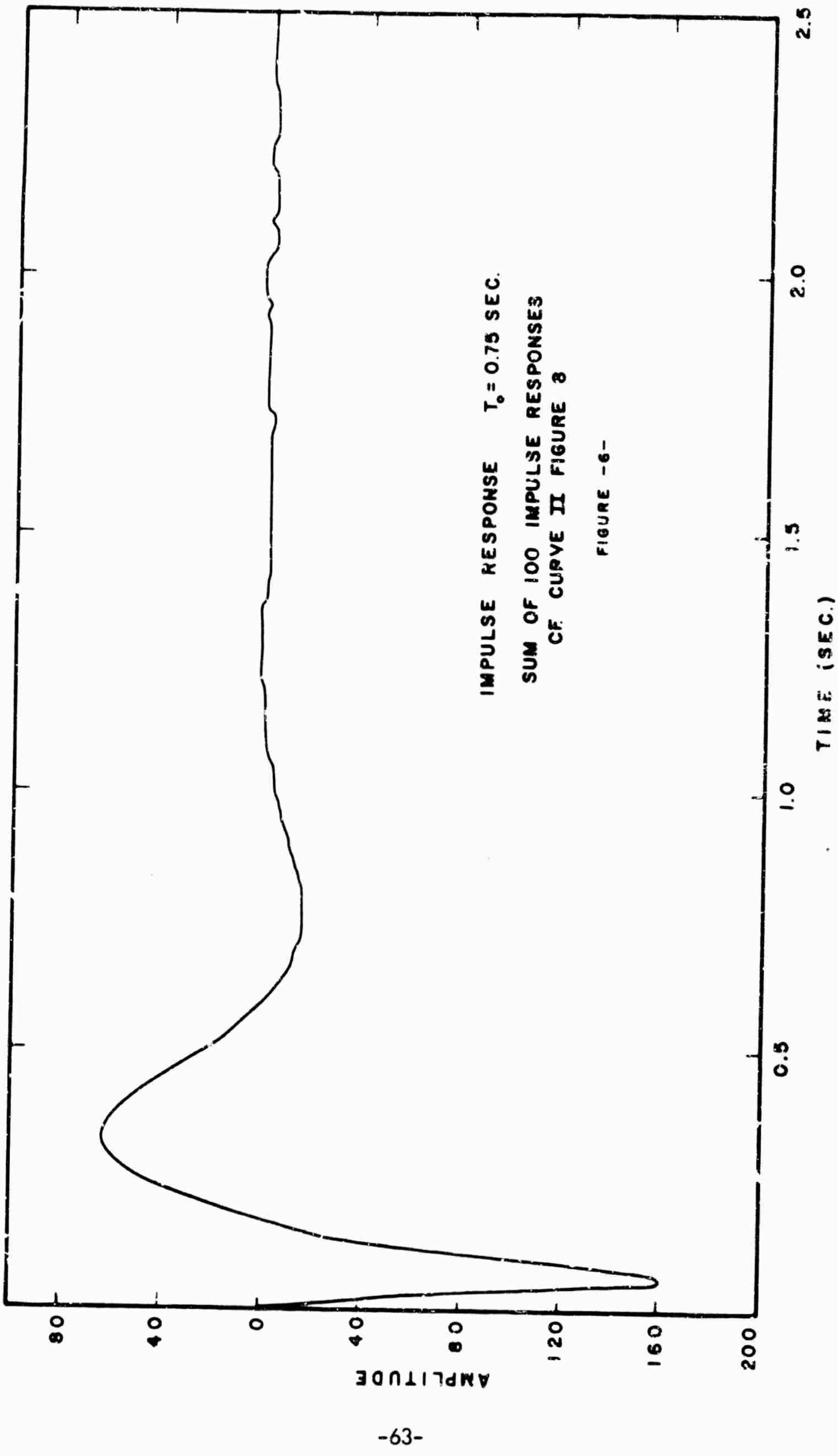


IMPULSE RESPONSE T_o = 1.04 SEC.
SUM OF 100 IMPULSE RESPONSES
FIGURE -4-



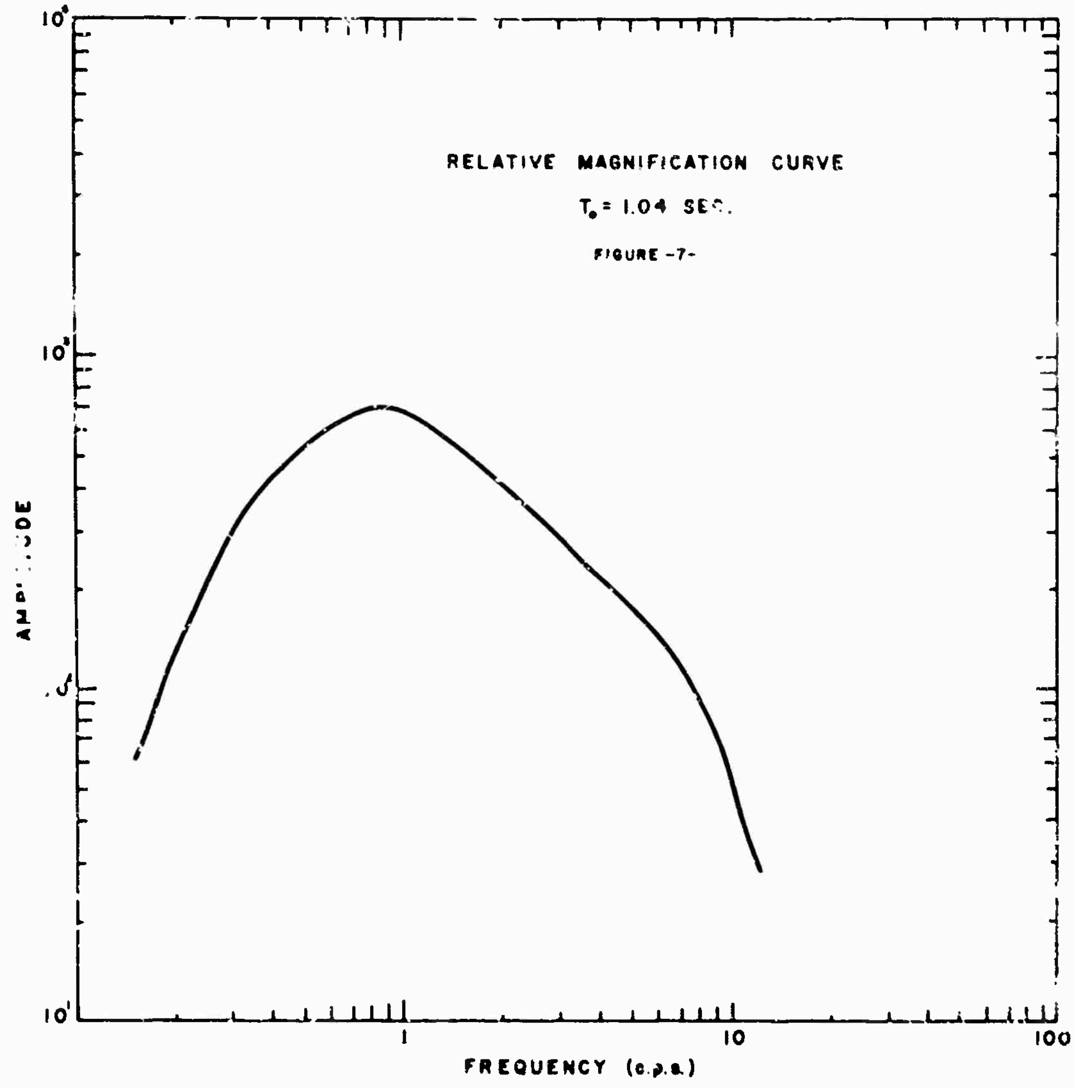
IMPULSE RESPONSE $T_o = 2.10$ SEC.
SUM OF 100 IMPULSE RESPONSES
CF. CURVE I FIGURE 8

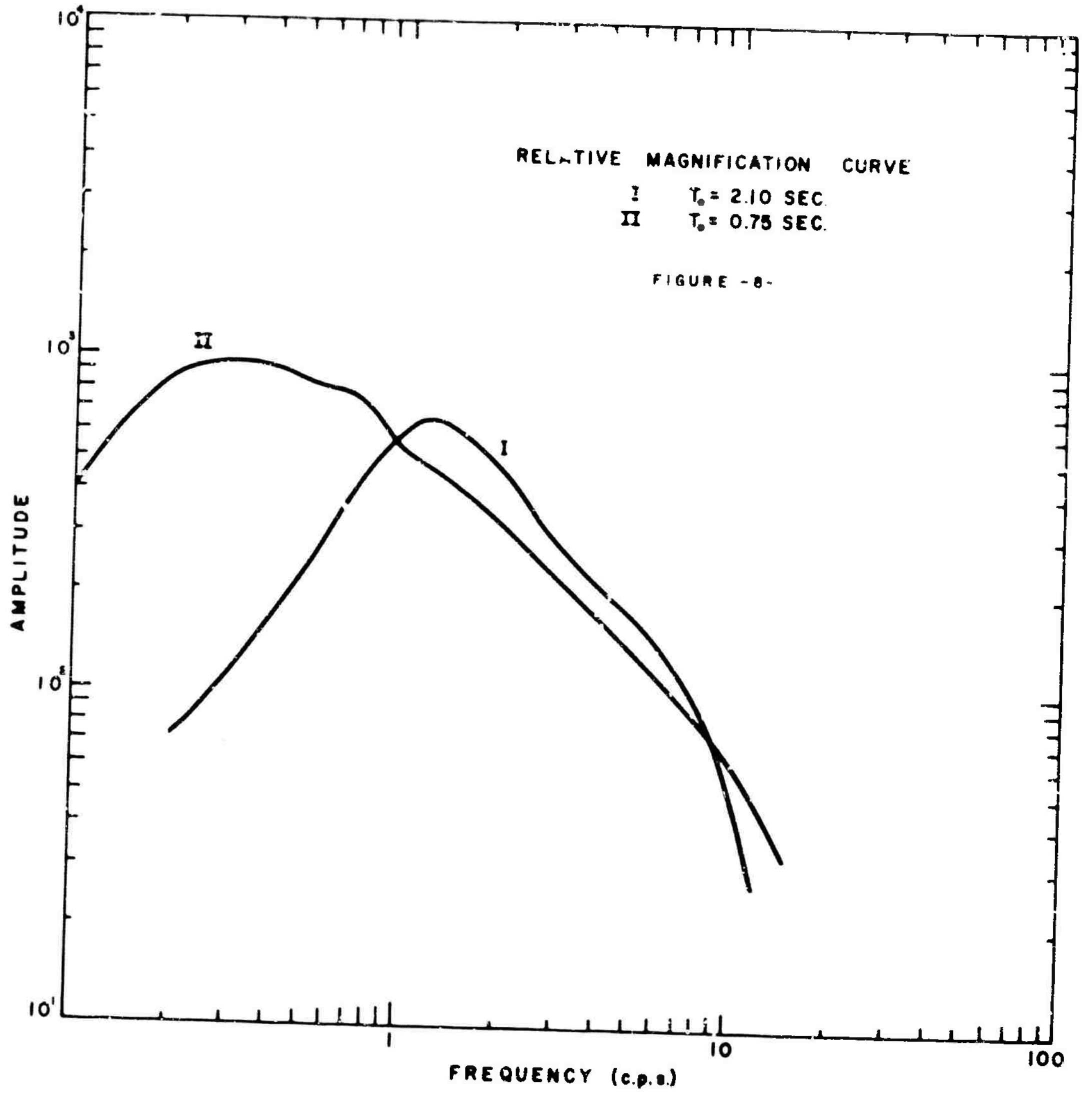
FIGURE -5-



IMPULSE RESPONSE $T_o = 0.75$ SEC.
SUM OF 100 IMPULSE RESPONSES
CF. CURVE II FIGURE 3

FIGURE -6-


RELATIVE MAGNIFICATION CURVE
T_o = 1.04 SEC.
FIGURE -7-
AMPLITUDE
FREQUENCY (c.p.s.)
1
10
100
10^1
10^2
10^3


RELATIVE MAGNIFICATION CURVE
I T_o = 2.10 SEC.
II T_o = 0.75 SEC.
FIGURE -8-
II
I
10^4
10^3
10^2
10^1
AMPLITUDE
1
10
100
FREQUENCY (c.p.s.)

Under present consideration are several modifications that will affect the operation of the units.

1. The prime concern is the engineering of the power supply. The system now in use has proved inadequate from an operation, cost and safety standpoint.

A system of DC - DC converters is currently being studied that will enable a single voltage battery pack to be utilized. It is felt that this system will result in a cost saving as well as reduction in down time. Full cost figures have not been compiled at this writing.

Coupled into the above would be a reduction of the amount and cost of field support gear, and a reduction in the overall cost of batteries.

2. A request for an automatic calibrate circuit has been rendered by Frank Crowley and Hank Ossing. In answer to this request are two systems.

The first system is the simplest. It consists of a motor driven cam that will actuate a switch sending a command to the calibrate relays. In this concept, pulse width cannot be controlled to any degree of accuracy, and extremely narrow pulses would be an impossibility. Where as, one of the requirements is for an impulse response, a second more complex system is being considered. It consists

of a motor driven wheel and works on a photo-pick off of a reflective portion or this wheel. A Schmidt trigger will detect the level change output of the photo cell and produce a sharp rise time pulse. This pulse will be differentiated and clipped to drive a monostable multivibrator by which we can control pulse width, which will inturn activate a relay to produce the desired cal pulse. This system is more reliable, adaptable to field changes and will produce a greater degree of timing accuracy.

The DC motors for either system will cost approximately $110.00 and will have a speed accuracy of 0.1%. In system II, torque is constant through out the revolution and of much less magnitude, thereby drawing less current which can be utilized by the control circuitry.

A cost breakdown estimate of both systems (see below) shows the adaptability of the second system to outweigh the 10% increase in cost. Battery drain is not a consideration, whereas, one system or the other must be utilized and both systems will draw approximately the same current. At this writing, circuit design has been completed and drive motors ordered for System II.

COST ESTIMATE PER UNIT

Item		System I		System II
Motor		$111.00		$111.00
Relays		36.20		36.20
Components		8.00		10.00
Fabrication & Installation	5mh.	30.00	8mh.	48.00
Total		$185.20		$207.20

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13. ABSTRACT

This report contains a complete description of a Portable FM Seismic Transmitting and Receiving System capable of unattended operation. It is specifically designed to broaden the capabilities of the portable seismic system developed under Contract AF19(628)-212. Each seismometer signal is preamplified and conditioned for FM transmission. The receiver recovers the signal and conditions it for recording, either directly or on magnetic tape.

A computer controlled system for the calibration of seismometers is described. The end product is a response curve in terms of both amplitude and phase.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
FM Transmitter and Receiver						
Seismometer Magnification						